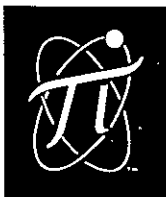
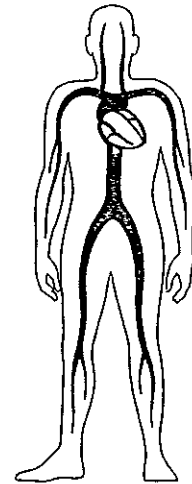


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TECHNOLOGY INCORPORATED

LIFE SCIENCES DIVISION

SPECIAL REPORT

SYSTOLIC TIME INTERVAL DATA ACQUISITION SYSTEM

(NASA-CR-151213) SYSTOLIC TIME INTERVAL
DATA ACQUISITION SYSTEM. SPECIALIZED
CARDIOVASCULAR STUDIES (Technology, Inc.,
Houston, Tex.) 61 p HC A04/MF A01 CSCI 06B

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Lyndon B. Johnson Space Center
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HOUSTON, TEXAS

SPECIAL REPORT:

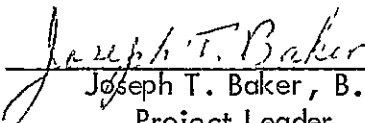
Systolic Time Interval Data Acquisition System

3 May 1976

SPECIALIZED CARDIOVASCULAR STUDIES

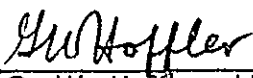
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PREPARED BY:



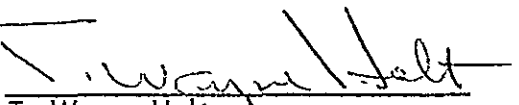
Joseph T. Baker, B.S.
Project Leader

CONCURRENCE BY:



G. W. Hoffler, M.D.
Chief, Cardiovascular Laboratory

APPROVED BY:



T. Wayne Holt
General Manager-Vice President
Life Sciences Division

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INTRODUCTION

Before man ever actually reached space there was serious conjecture by the scientific community as to the effects of spaceflight on the human organism. Opinions on this subject ranged from complete astronaut disability to no deleterious effects at all. After the highly successful flights of Mercury, Gemini, Apollo, and Skylab we now know for certain that man can function effectively in space for periods as long as three months without a lasting, harmful effect on his body. This is not to say that space has no effect on the human organism but that these effects are subtle and difficult to document.

Medical investigations of the effects of spaceflight became more and more sophisticated as each series of missions became reality. The investigation of the human organism's reaction to the spaceflight environment reached an apex during the historic Skylab missions. Despite the years of thought and careful planning, every experiment could not be flown in the Skylab, so a few experiments, that were very worthwhile in terms of simplicity and amount of information elicited, were not flown in Skylab but were utilized in the pre- and postflight medical evaluations of crewmembers. One such experiment was the determination of the Systolic Time Intervals of the astronaut crewmembers. The Systolic Time Intervals are basically a group of measurements in the time domain made from both the electrical and mechanical events present in the cardiopulmonary cycle. The measurements are obtained via noninvasive sensors and signal conditioners.

The subject of this Special Report deals with the development of the Systolic Time Interval Data Acquisition System. This instrumentation was developed in response to the need for a light weight, reliable, self-contained instrument that could acquire the four

basic parameters needed to compute systolic time intervals and provide these signals to a variety of recording devices. Previously, these signals had commonly been acquired by separate instruments, sometimes made by a variety of manufacturers, which was wasteful of space, weight, power and extremely inconvenient for the investigator. In response to this problem the personnel of Technology Incorporated designed and constructed a system for the acquisition of the systolic time interval parameters. This system has gone through many revisions and updates, but the device presented here is the final model. This device, in its present form, was used with great success in the Shuttle Simulation Test II and is scheduled to be used in the Johnson Space Center Bed Rest Study. Earlier versions were utilized throughout the Skylab missions. The device is small, light weight, self-contained and interfaceable with a variety of recording equipment such as analog tape recorders, strip charts and even computers.

The four parameters that compose the Systolic Time Intervals are as follows:

- A. Electrocardiogram – the Q-wave of the ECG is used for timing purposes.
- B. Carotid Pulse – this signal is obtained by the transducer placed over the right or left external carotid artery.
- C. Phonocardiogram – this signal is obtained from the microphone transducer located on the chest. It records primarily the first (S_1) and second (S_2) heart sound.
- D. Respiration – all measurements for S.T.I. calculations should be made during the expiratory phase of respiration. This rule serves to stabilize the measurements which are somewhat different during the various phases of respiration. Respiration may be recorded by several methods; these methods are documented elsewhere.

Figure 1 shows the various transducers in place on a subject. All sensors are noninvasive and the measurements themselves are entirely painless. Calculations for the various para-

meters are listed below and may be correlated with Figure 2.

1. R-R interval from the ECG determines instantaneous heart rate prior to the beat to be measured. Measurement is in milliseconds.
2. Total electro-mechanical systole ($Q-S_2$) - is measured from the onset of the ECG Q-wave to the onset of the second heart sound (S_2). Measurement is in milliseconds.
3. Ejection Time (ET or LVET) is measured, from the onset of carotid upstroke to the incisure. Measurement is in milliseconds.
4. Pre-ejection period (PEP) is computed by subtracting ET from $Q-S_2$.
5. PEP/ET ratio is computed directly.

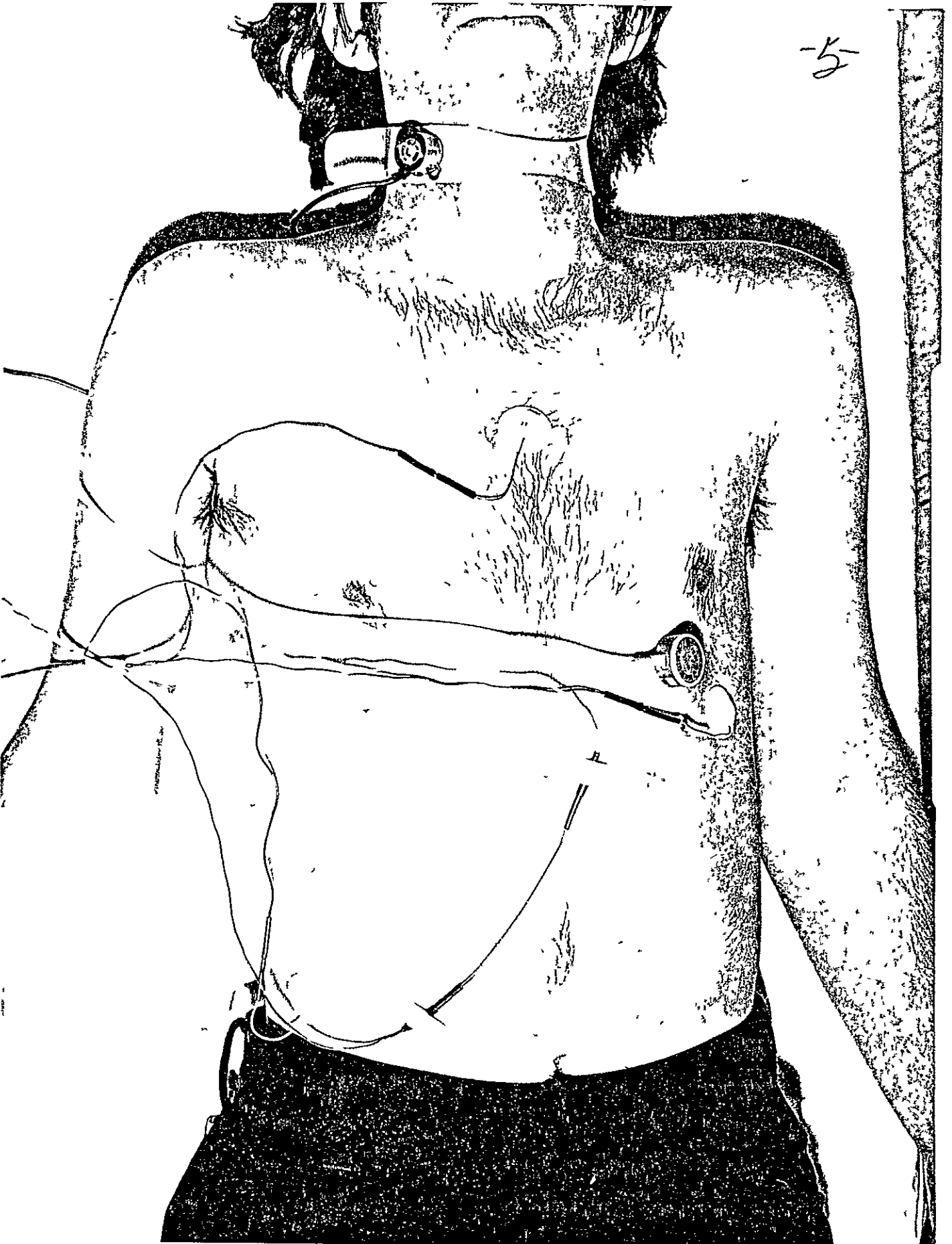
Since some of these measurements are heart rate dependent they must be corrected for variations in heart rate before a direct comparison of data can be made. A number of investigators have proposed methods for correcting values according to heart rate and several formulae are used at present, depending on the laboratory and individual investigators.

Measurement of the Systolic Time Intervals has been used in the assessment of Left Ventricular Function (LVF), as a sensitive indicator of change in LVF during stress tests, an indicator of myocardial contractility and as a possible screening test to indicate patients in the early stages of heart failure. Systolic Time Intervals may also lead to an effective, noninvasive screening method for potential victims of heart disease and as a method of following post myocardial infarction patients without the use of costly and dangerous invasive tests and the considerable expense of the hospitalization the tests require.

It is not the intention of this report to delve deeply into the intricacies of either the use or interpretation of Systolic Time Intervals in the medical community but to present

a device for the acquisition of this data. It is sufficient to say that the noninvasive measurement of systolic time intervals is rapidly becoming a useful clinical tool. A bibliography is provided for those who's interest is strong enough to pursue the matter of interpretation and uses of Systolic Time Intervals further.

FIGURE 1



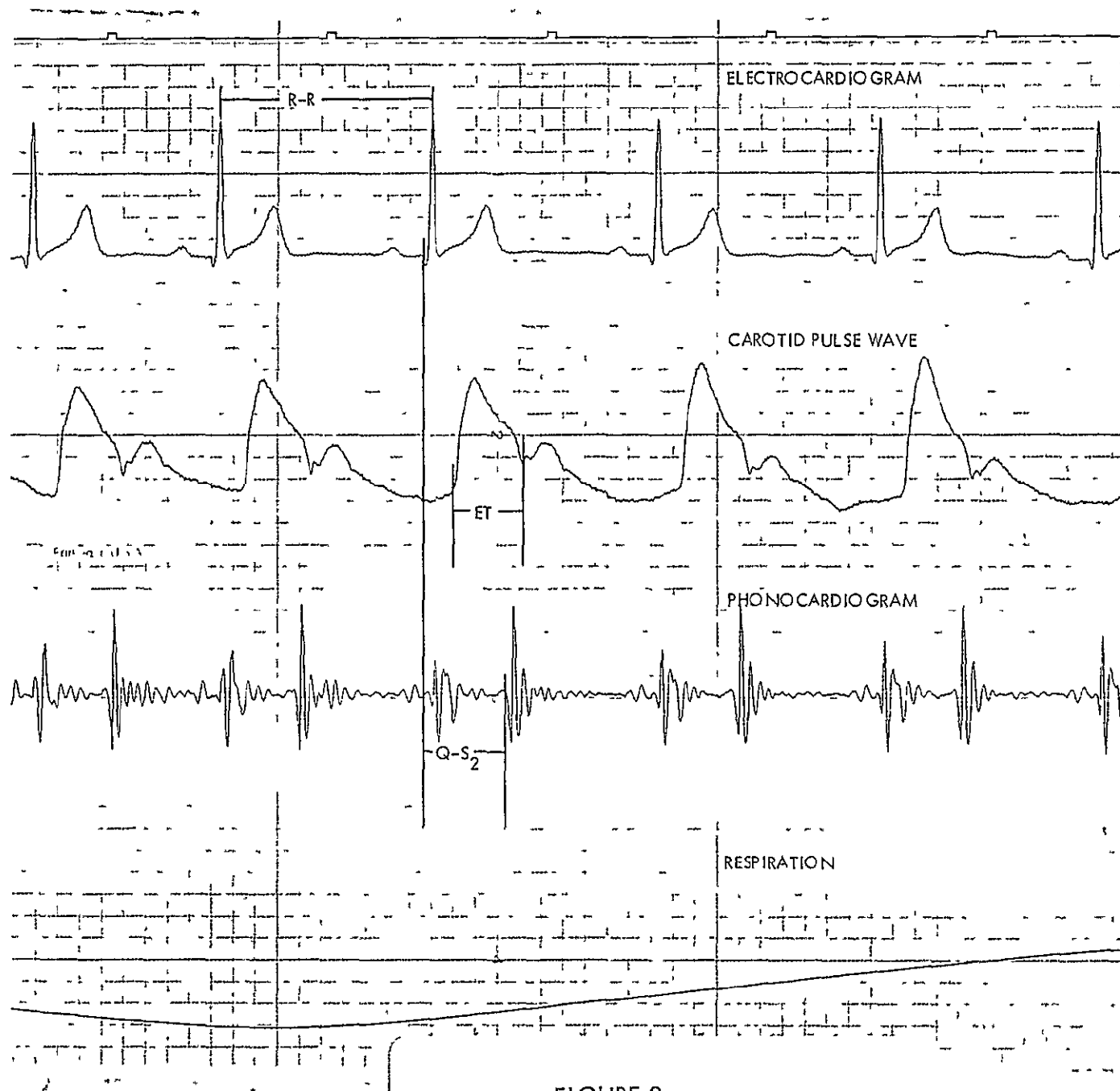


FIGURE 2

SECTION 1 FRONT PANEL CONTROLS

The Systolic Time Interval Data Acquisition System consists of a number of signal conditioners and sensors. The signal conditioners will be dealt with in Section II.

To determine the Systolic Time Intervals of a patient, four fundamental signals are required.

These are as follows

1. Electrocardiogram - usually a lead I or equivalent.
2. Phonocardiogram - obtained from the 4th or 5th intercostal space at the left sternal border.
3. Carotid Pulse - obtained from the right or left external carotid artery.
4. Respiration - two options are present in the system, a mercury in silastic strain gauge which is attached to the patients abdomen or temperature sensitive transducer placed in front of either nose or mouth. Either is satisfactory to detect the phase of respiration but one method is sometimes more desirous than the other with a given patient.

The physical housing for these signal conditioners is presented in Figures 3 and 4 which are a front and back view of the housing which is commonly called a card cage. All circuits for signal conditioning, AC power conversion, and signal output are contained in this cage. These electronics are connected to a front panel control section which is seen in Figures 5 and 6 which are a front and back view respectively. Gain, power and offset adjustments are controlled from this panel. These controls are as follows

- A. Power - controls AC power to unit - typically 117 VAC
- B. SG-PNG-Strain Gauge Pneumogram
 1. Gain - controls signal level in DV volts
 2. Zero - controls offset adjustment
- C. Phono - Phonocardiogram gain control in DC volts
- D. T-PNG-Thermo Pneumogram - gain control in DV volts

E. Carotid - Gain control in DC volts

F. ECG-Gain-Switchable gain control for single lead Electrocardiogram

The control panel will fit any standard 19" instrument rack and occupies 5.25" of vertical space. The card cage is located anywhere convenient and is limited only by the cable length connecting it to the control panel.

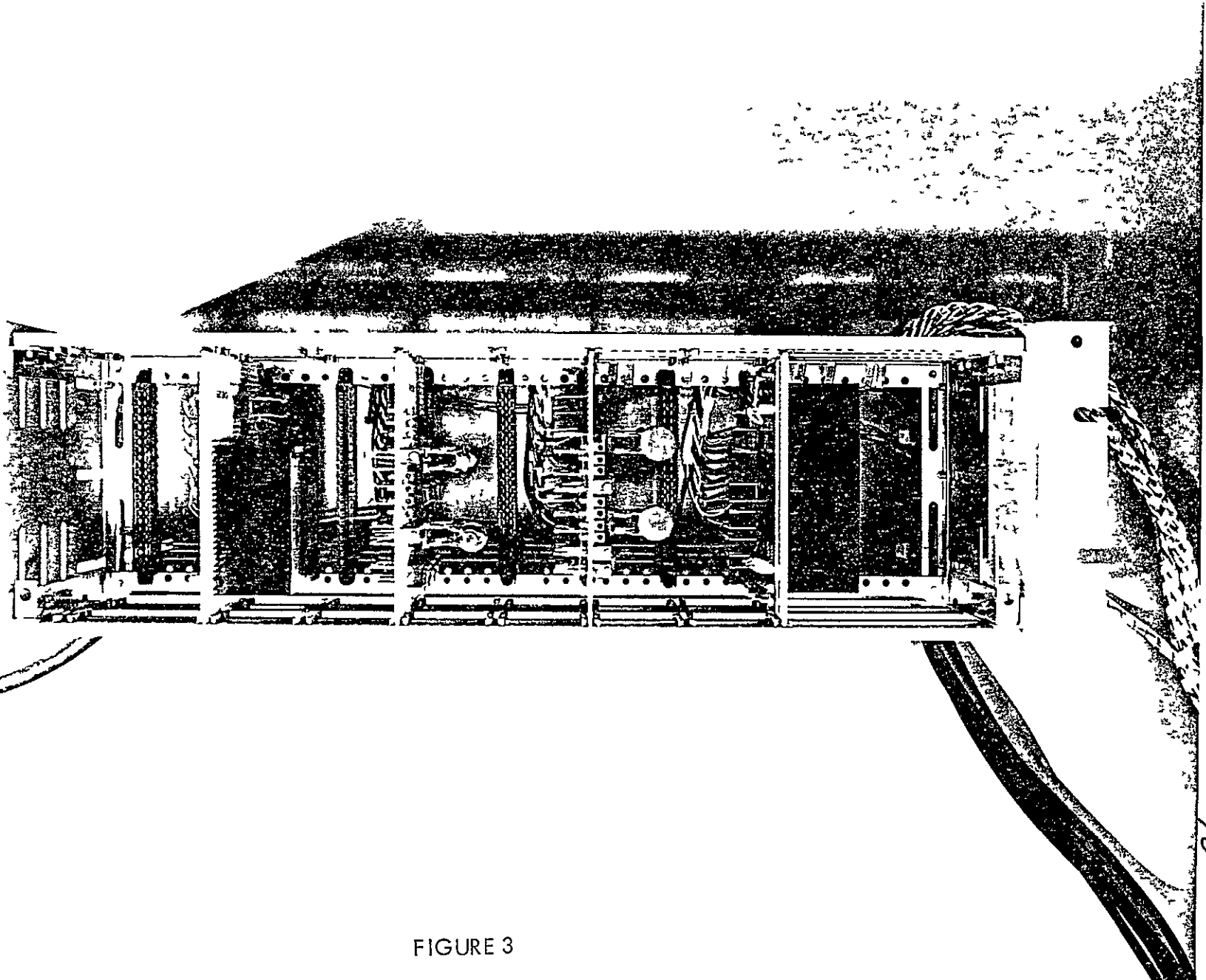


FIGURE 3

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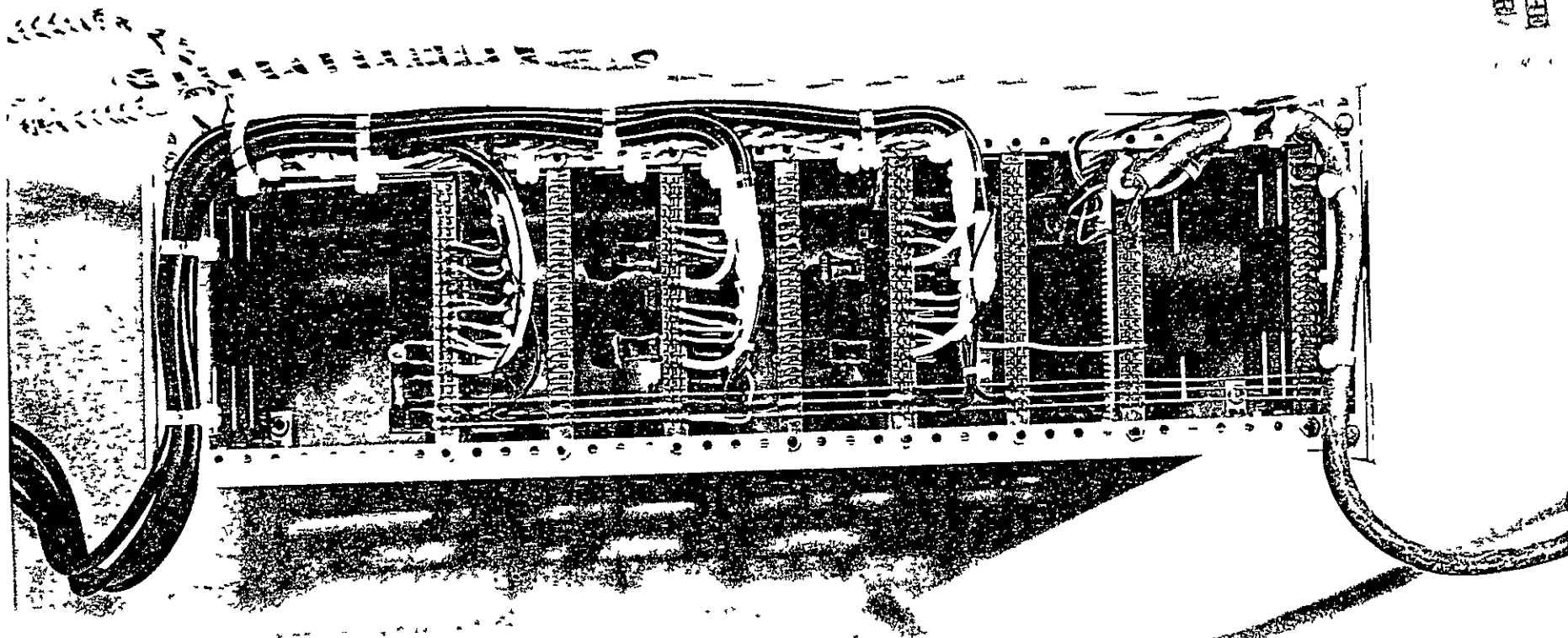


FIGURE 4

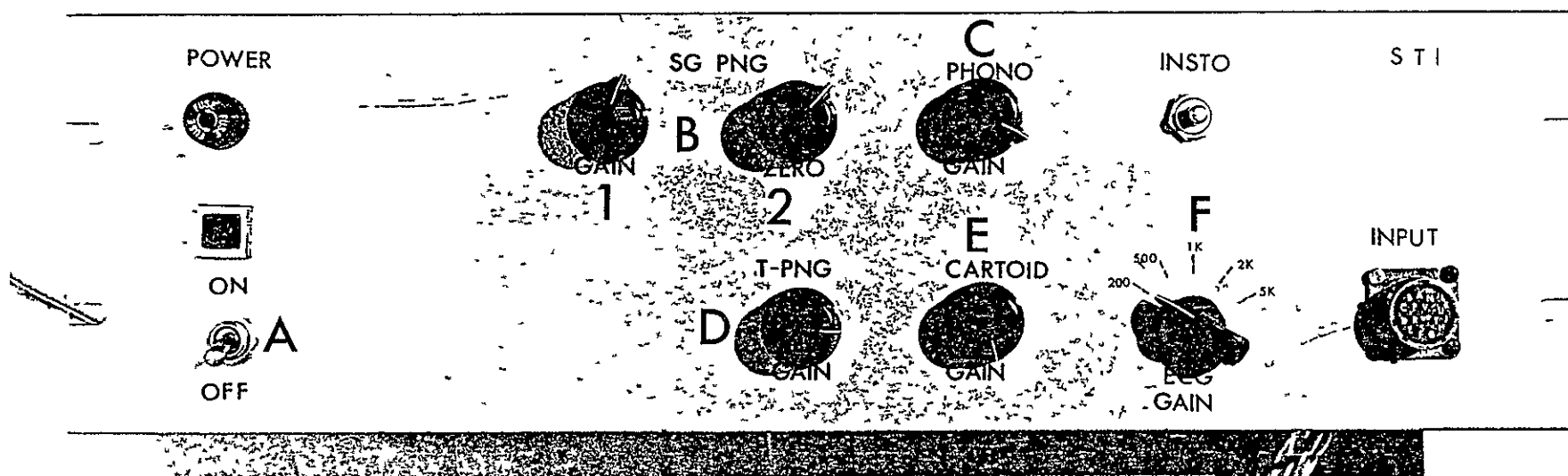
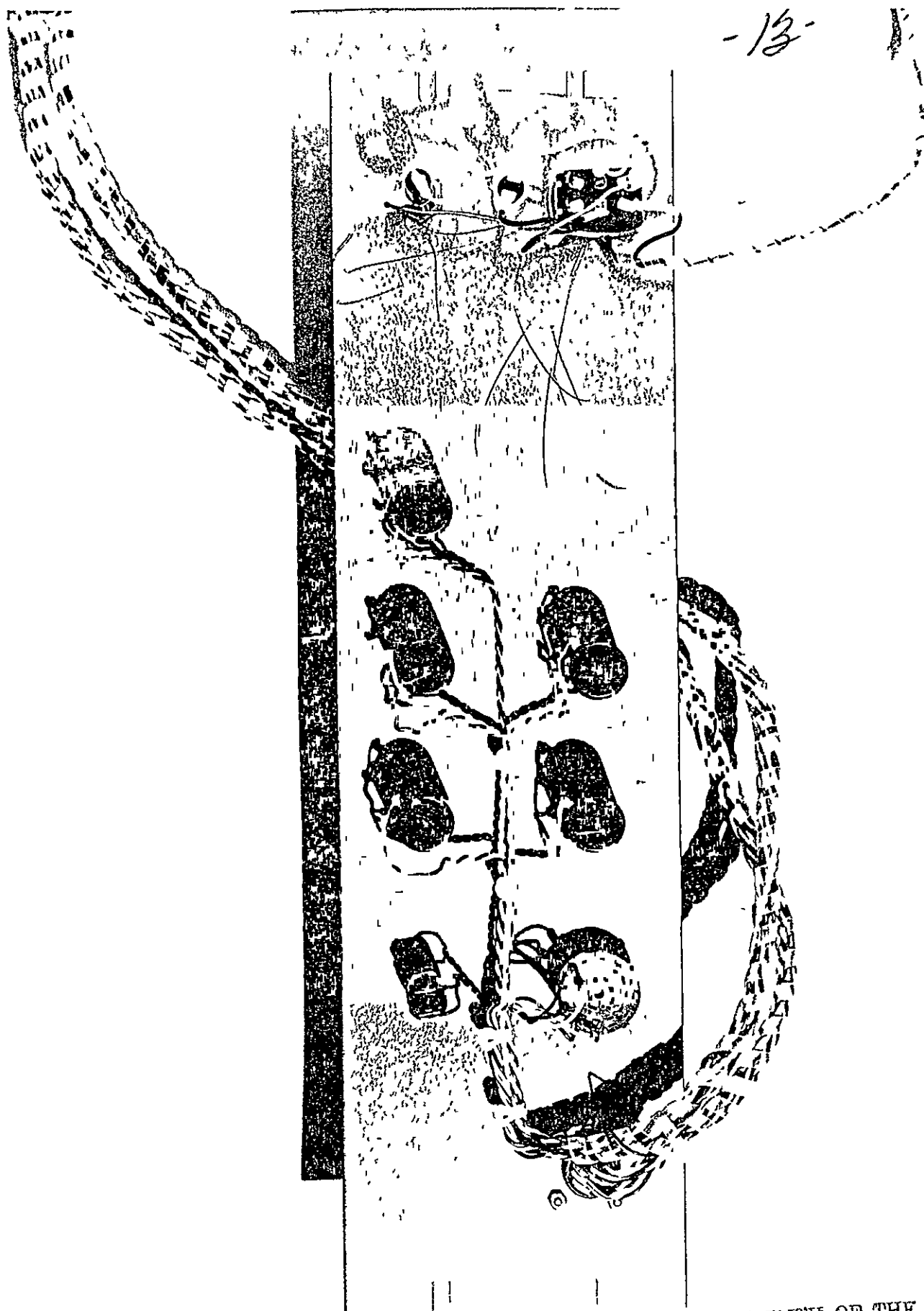


FIGURE 5



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SECTION II SIGNAL CONDITIONERS AND POWER SUPPLY

In this section the individual signal conditioners will be identified. The following scheme will be utilized to provide uniformity and ease of use. Each signal conditioner will be identified and its function described. The description will be followed by a schematic of the signal conditioner representing the connections of each of the components and its connection to the back plane and other signal conditioners.

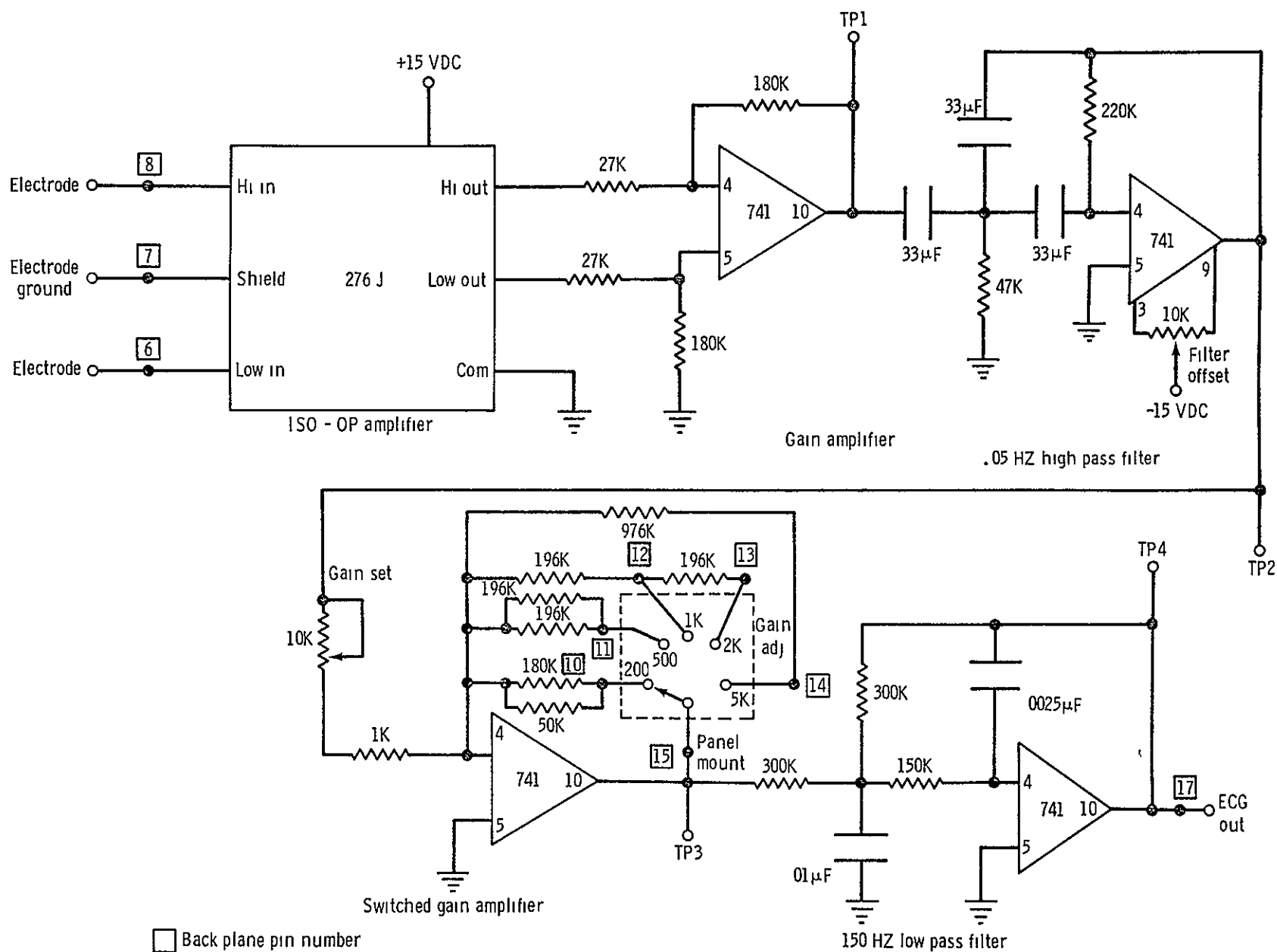
A. Electrocardiogram (ECG) Amplifier

The ECG amplifier provides amplification for the patient's electrocardiogram signal and completely isolates the patient from the surrounding electrical environment. This isolation eliminates the possibility of electrical shock that might be hazardous to the patient. The ECG amplifier has the following electrical specifications

Bandpass - .05 Hz to 150 Hz

Gain - Max = X5000 switchable in the following steps X-200, X-500, X1000, X2000 and X5000

Electrical schematics and connections are detailed in Figure 7.



Electrocardiogram amplifier board No 4

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B. Carotid Pulse and Phonocardiogram Amplifiers

The carotid pulse and phonocardiogram amplifiers are physically located on the same board #2 but are effectively separate in operation and will be treated this way.

The carotid amplifier provides amplification and filtering for the carotid transducer signal. The electrical specifications are as follows.

Bandpass – DC – 150 Hz

Gain – Infinitely variable from X150 to 1500

Electrical schematics and connections are detailed in Figure 8.

Phonocardiogram Amplifier – provides amplification and filtering for the phonocardiogram microphone. The electrical specifications are as follows.

Bandpass – DC to 400 Hz

Gain – Infinitely variable from X5 to X500

Electrical schematics and connections are provided in Figure 9.

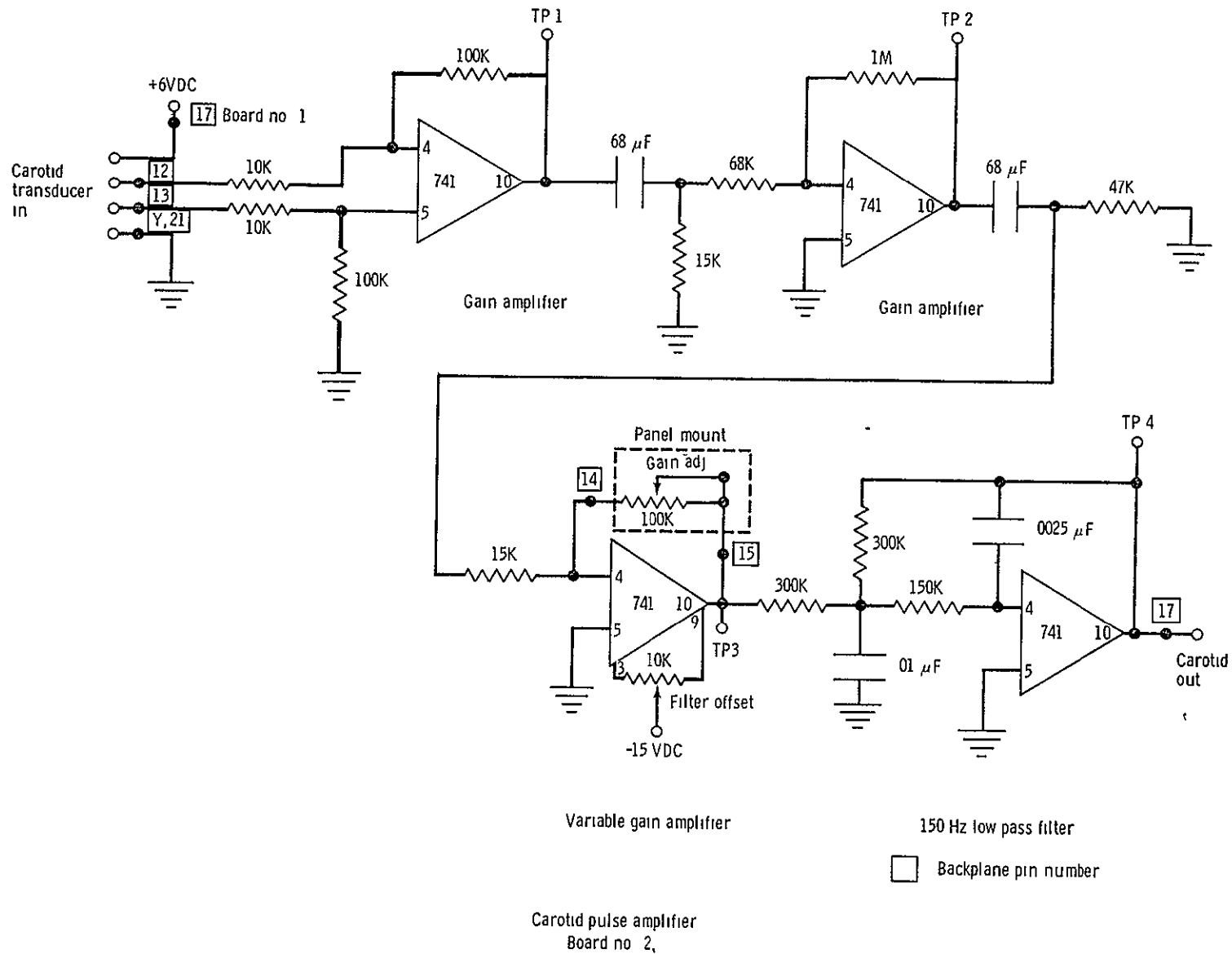
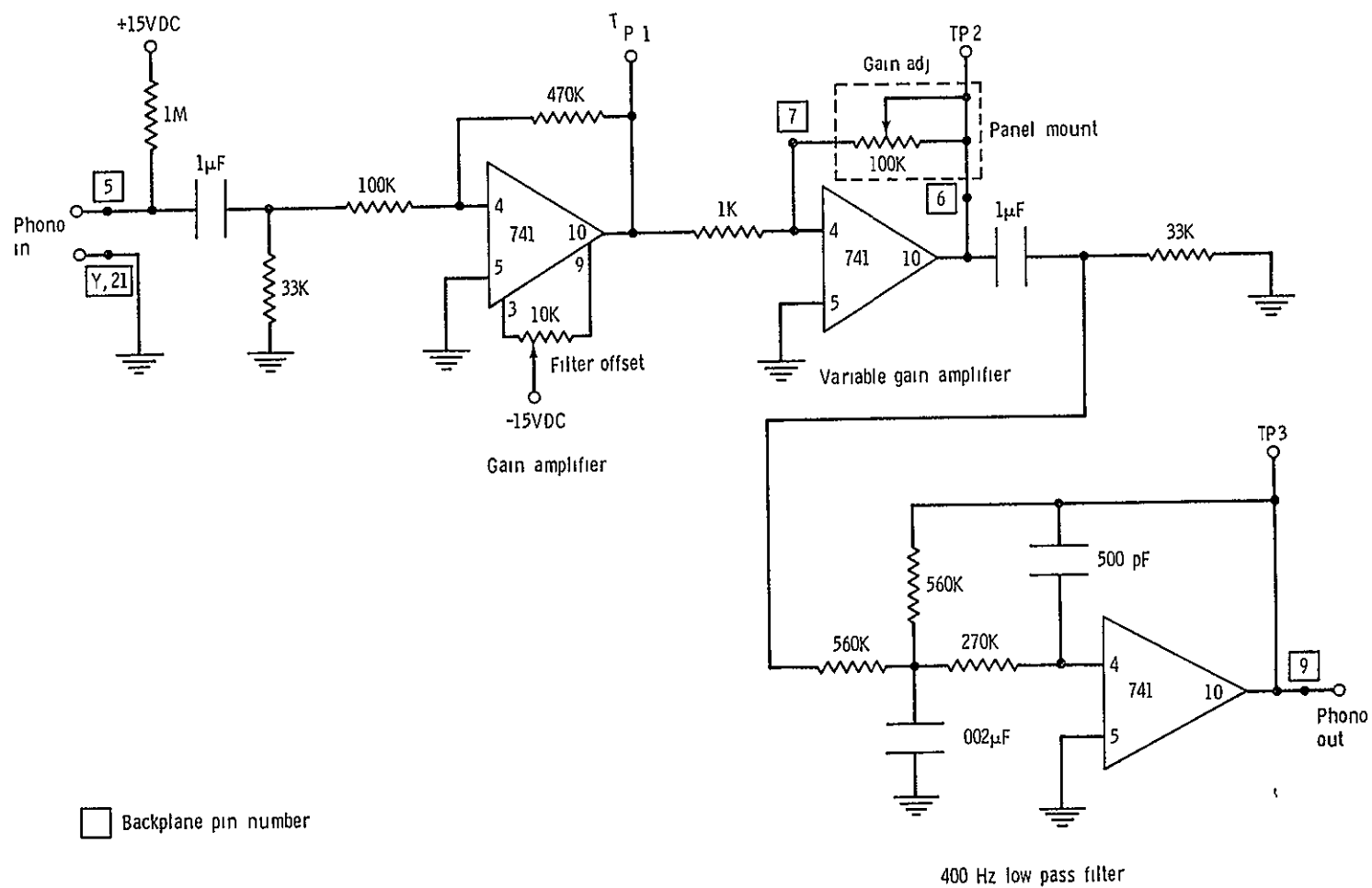


FIGURE 8

66



Phonocardiogram amplifier board no 2

FIGURE 9

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C. Pneumogram

Two methods for the measurement of respiration are provided. The components of these two signal conditioners are physically located on the same board #3 but their individual functions are totally separate and will be treated as such.

Strain gauge pneumogram – is essentially a Wheatstone bridge where one arm of the bridge is a mercury in silastic strain gauge. Amplification and filtering of the resistance changes in the strain gauge are provided by this amplifier. The electrical specifications are as follows.

Bandpass – DC to 20 Hz

Gain – Infinitely variable from X220 to X11,000

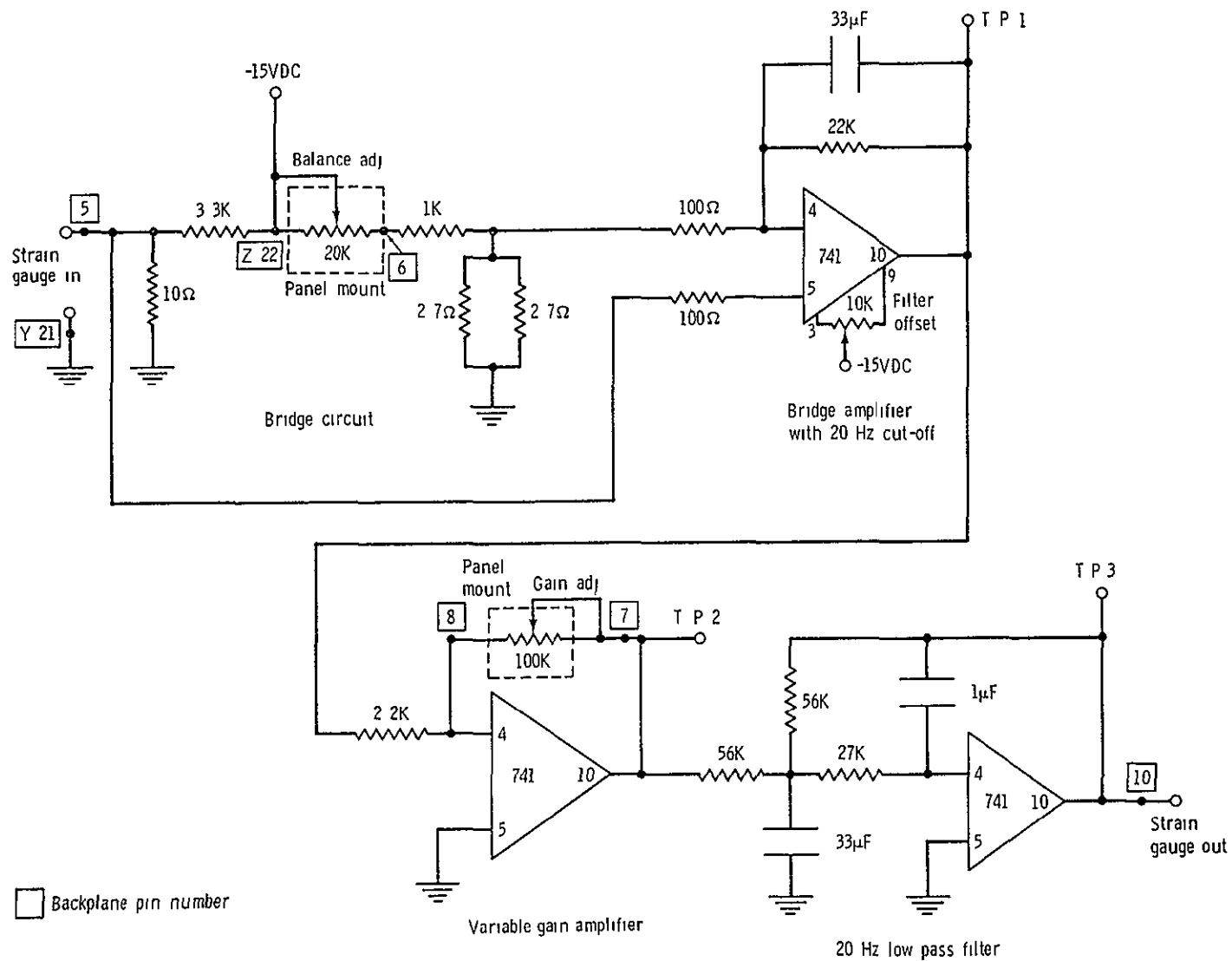
Electrical schematics and connections are provided in Figure 10.

Thermal-pneumogram – provides amplification and filtering to the temperature sensitive transducer. Passage of the patient's breath over the transducer causes a change in temperature which results in a varying DC signal directly proportional to respiration. The electrical specifications are as follows

Bandpass – .05 Hz to 20 Hz

Gain – Infinitely variable from X10 to X100

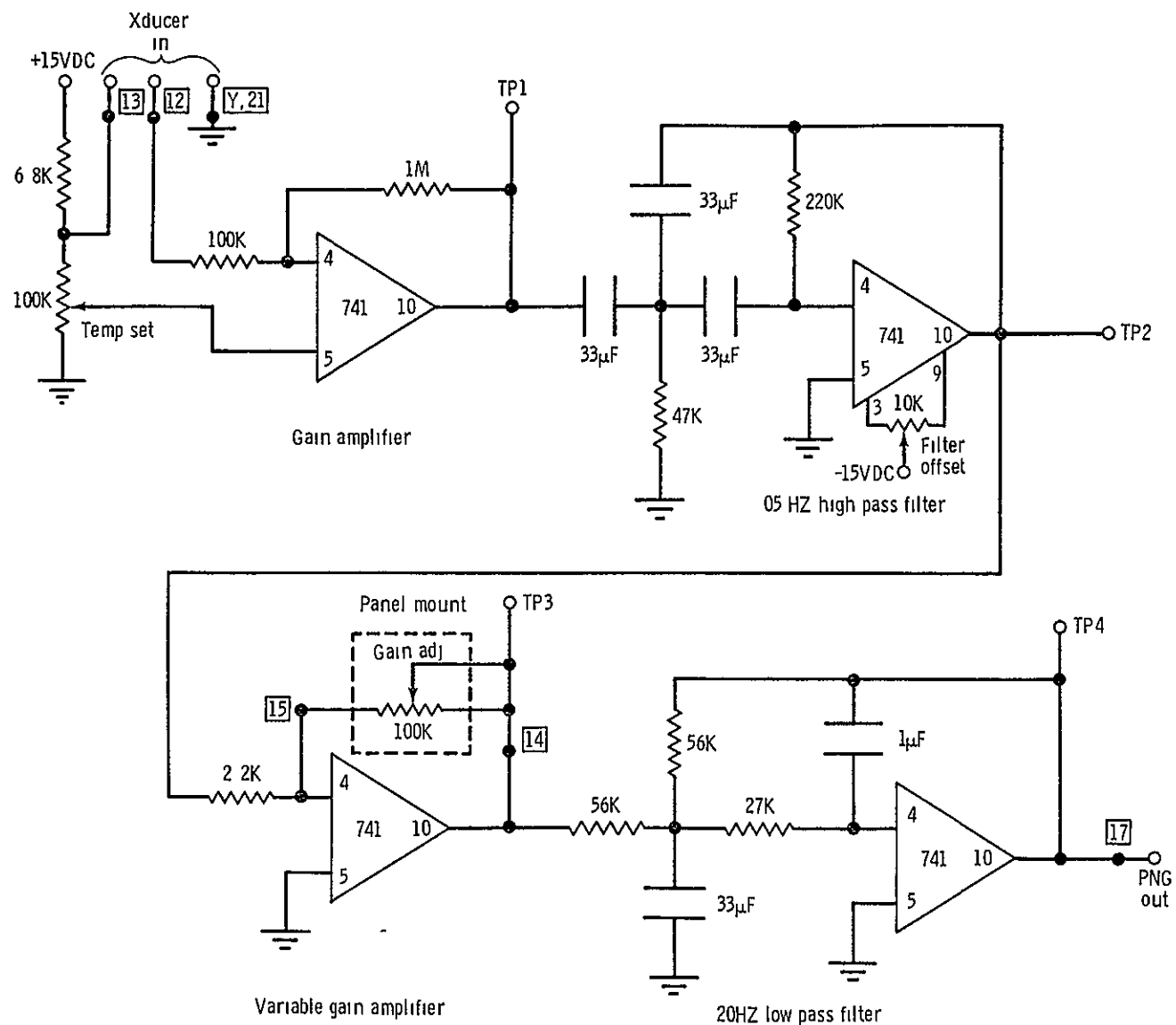
Electrical schematics and connections are provided in Figure 11.



Strain gauge pneumogram amplifier board no 3

FIGURE 10

Handwritten signature



Thermo-pneumogram amplifier
Board no 3

FIGURE 11

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D. DC Power Supply

The power supply for the entire unit is derived from a modular power supply. Unregulated 117 VAC power is converted to a regulated ± 15 VDC with a current capacity of 200 milliamperes. The + 15 VDC side of the power supply is tapped to provide a + 6 VDC power source for the Carotid Pulse Transducer. The electrical specifications are as follows

± 15 VDC Supply

Input 117 VAC unregulated

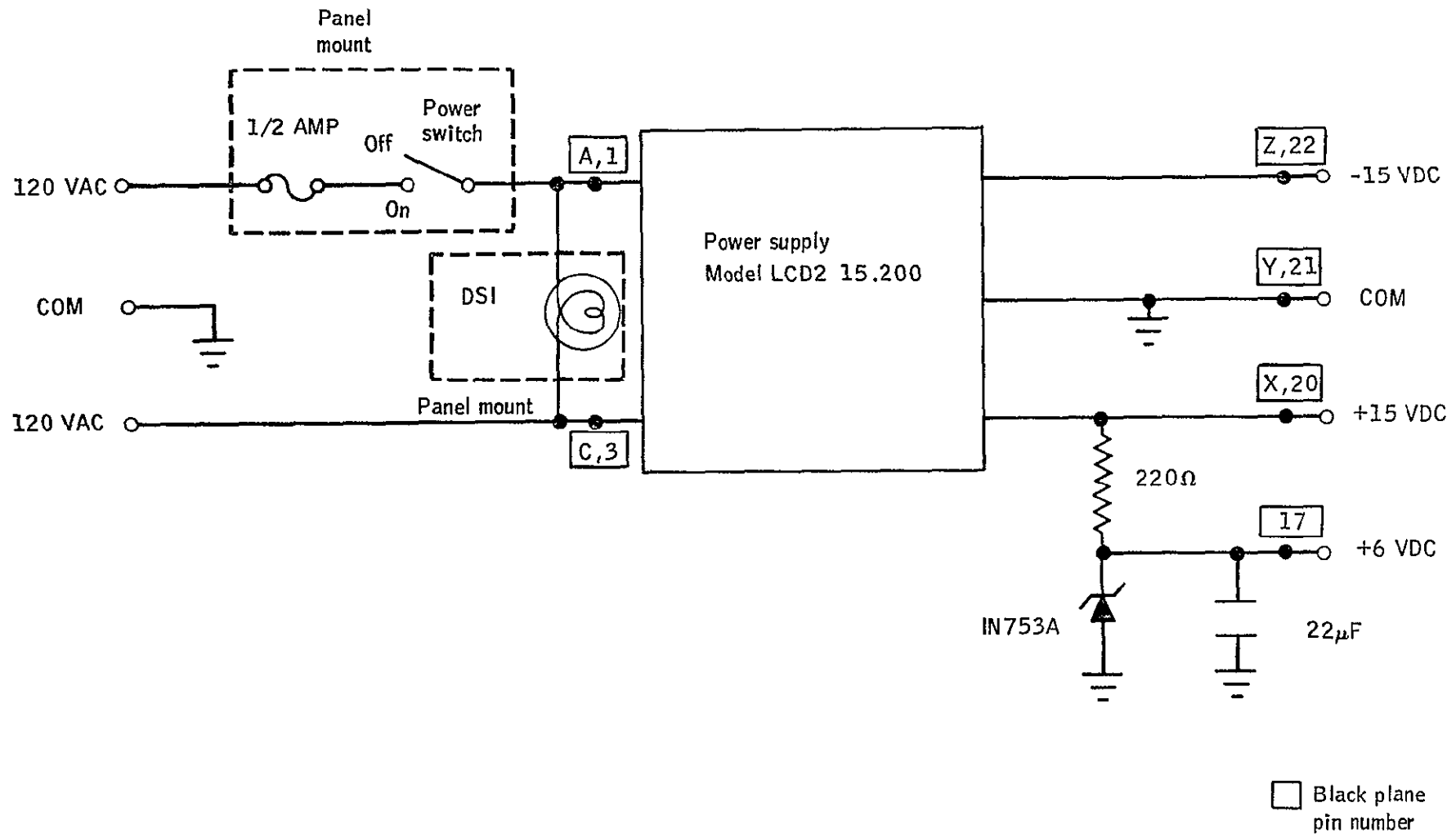
Output ± 15 VDC regulated to $\pm .01\%$ @ 200 milliamperes

+ 6 VDC Supply

Input + 15 VDC

Output + 6 VDC

Electrical schematics and connections are provided in Figure 12.



DC power supply board no. 1

FIGURE 12

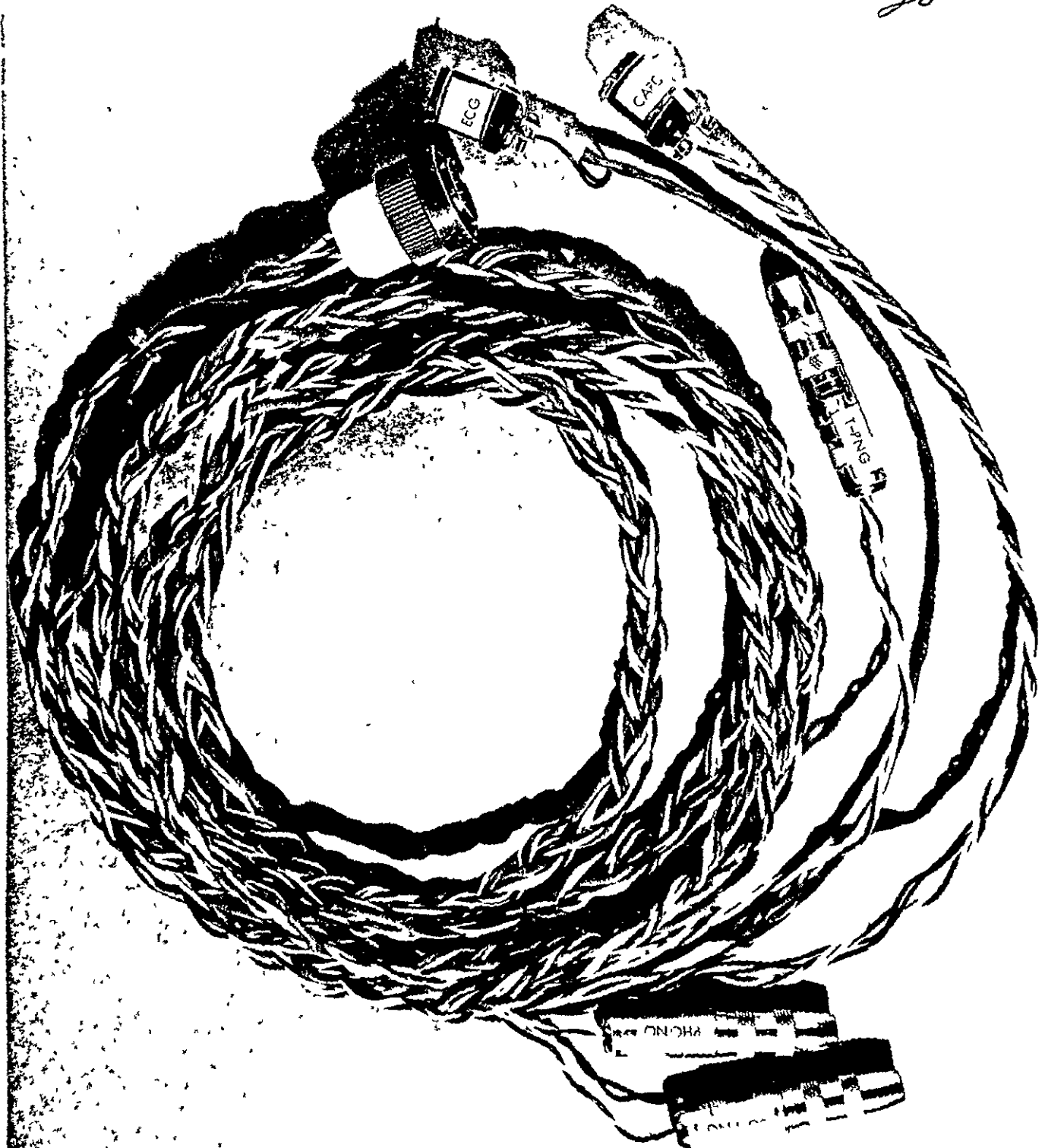
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SECTION III SENSORS AND TRANSDUCERS

The sensors used to acquire the Systolic Time Interval signals are supplied by several manufacturers, and several are built by the laboratory staff. To facilitate the handling and application of the sensors, a harness was constructed to extend the sensor cable length and facilitate change out of sensors. This harness is shown in Figure 13. The combined length of the harness and sensor cables is 20 feet (Figure 14) and plugs directly into the front panel via a multipin connector. The individual sensors that are attached to this harness will be discussed next.

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FIGURE 13

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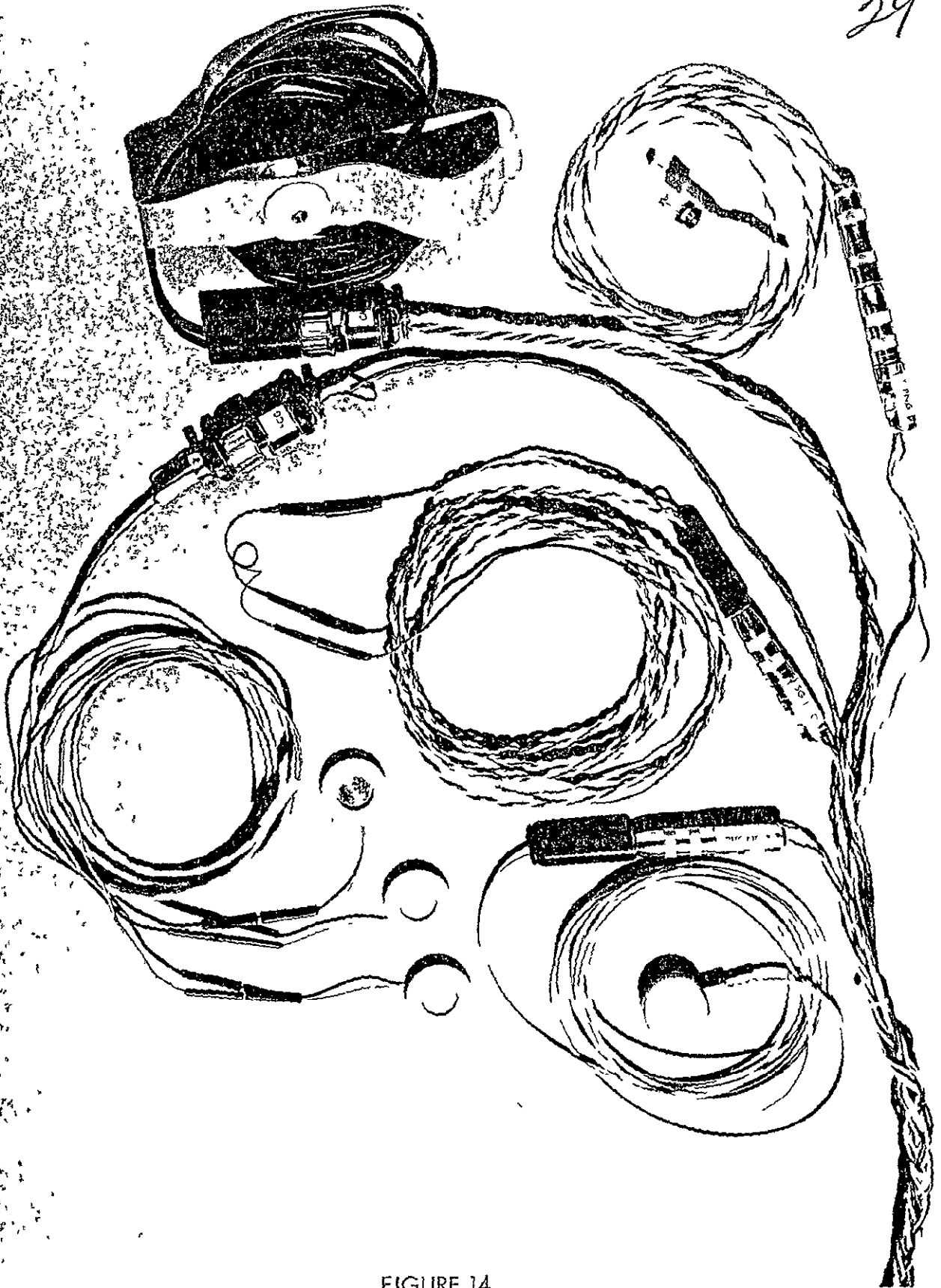


FIGURE 14

A. Carotid Pulse Sensor

The carotid pulse sensor is a Hewlett-Packard force transducer, Model APT-16. This transducer requires an excitation voltage of 6 VDC at 20 maDC. This voltage is supplied from the DC power supply contained in the system. The natural frequency of the APT-16 transducer is 300 Hz with an output impedance of 2.5K ohms and an output ripple of 10 mv RMS. Figure 15 shows the face of the transducer with the weighted strap that serves to hold it in the proper position over the external carotid artery. Figure 16 shows a close up of the transducer and positioning strap in place on a subject's external carotid artery. The black lines indicate the course of the artery and the proper positioning of the transducer over the artery. This transducer has proven to be rugged and dependable in daily use.

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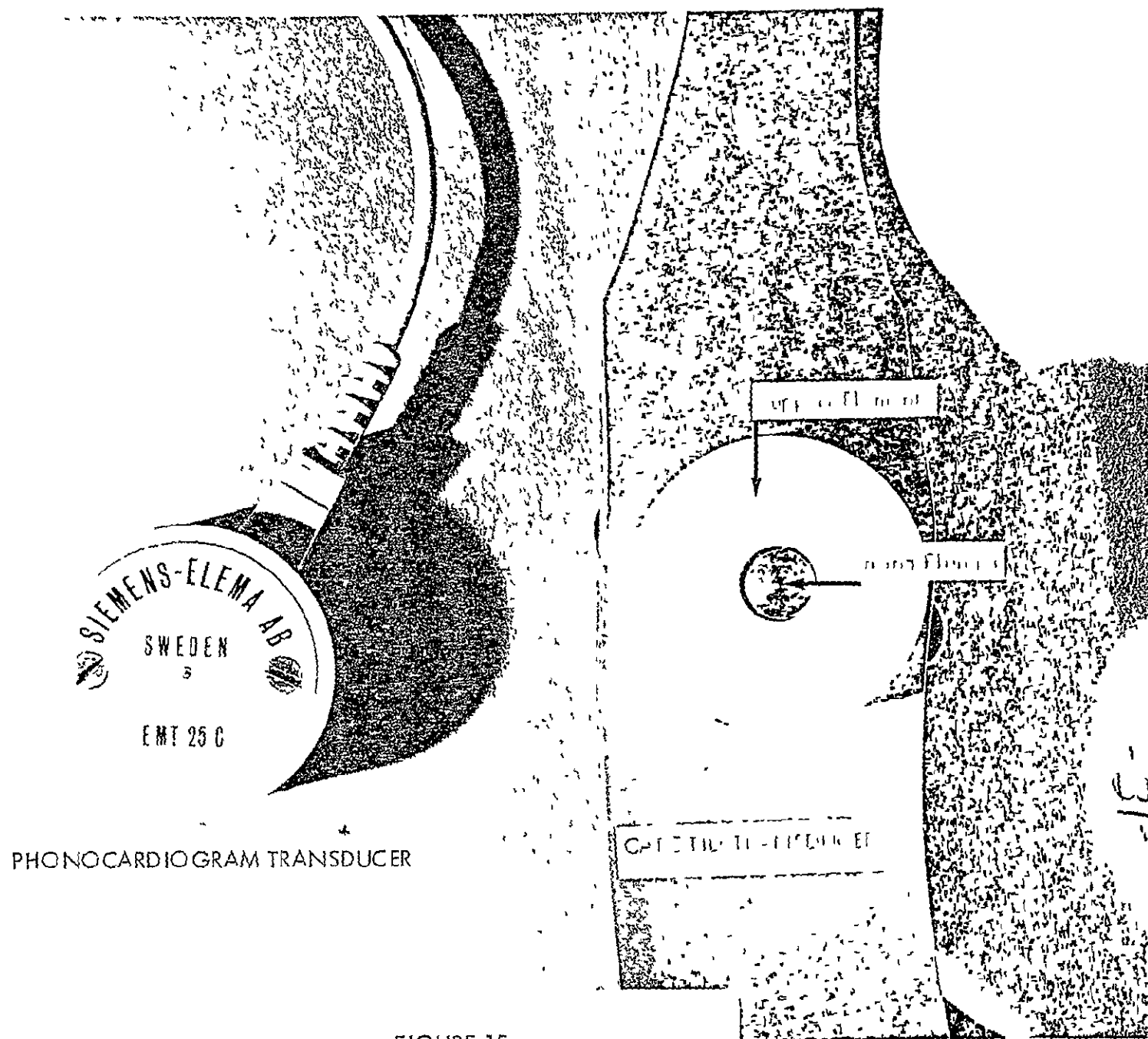


FIGURE 15



FIGURE 16

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B. Phonocardiogram Transducer

The phonocardiogram sensor is a piezo-electric accelerometer type microphone. The microphone is made by the Siemen Company and is the model EMT-25C as pictured in Figure 15 with its connecting cable. The low weight of the transducer matches the mechanical impedance of the chest wall to ensure the most favorable conditions for signal pickup. Output impedance of the transducer is less than 40 Kohms with its natural frequency being at approximately 1000 Hz. The usual method of application is with double backed tape. This method is convenient and provides a solid contact without the use of a coupling agent. The microphone itself has proved to be extremely rugged but several failures have been experienced with the microphone cable. It is recommended that this cable be handled with great care since it does seem to be fragile.

C. Pneumogram

1. The strain gauge pneumogram is fashioned from medical grade silastic tubing and metallic mercury. The length of the gauge is approximately three inches with a resistance of .1 ohm. This resistance forms one leg of a wheatstone bridge amplifier such that an increase in resistance, e.g., lengthening of the silastic tube, results in an increasing DC voltage at the output of the signal conditioner. This transducer is typically attached to the left rib margin on one side and the abdomen on the other side to indicate movements of the abdomen and rib cage with respiration. The strain gauge (Figure 17) has a useful life span of about three months if handled with care

2. The temperature sensitive pneumogram is a National Semiconductor integrated circuit, the LX5600 in the T0-46 package. The integrated circuit itself is shown in Figure 17 ready to be inserted into any acceptable housing which will position it before the patients nose or mouth. As the patients respiration changes the temperature of the LX5600 the signal conditioner senses this change and outputs a varying DC voltage that corresponds directly with the patient's phase of respiration. Power consumption is approximately 3mA and linearity is better than 1%. While the integrated circuit itself is extremely durable the circuit stability suffers greatly in areas of high air movement e.g., air conditioner on-off cycle, unless the transducer is very well shielded from ambient drafts. Despite the drawback the sensor has proven useful in patients where injuries to the chest or abdomen precluded use of the strain gauge unit.

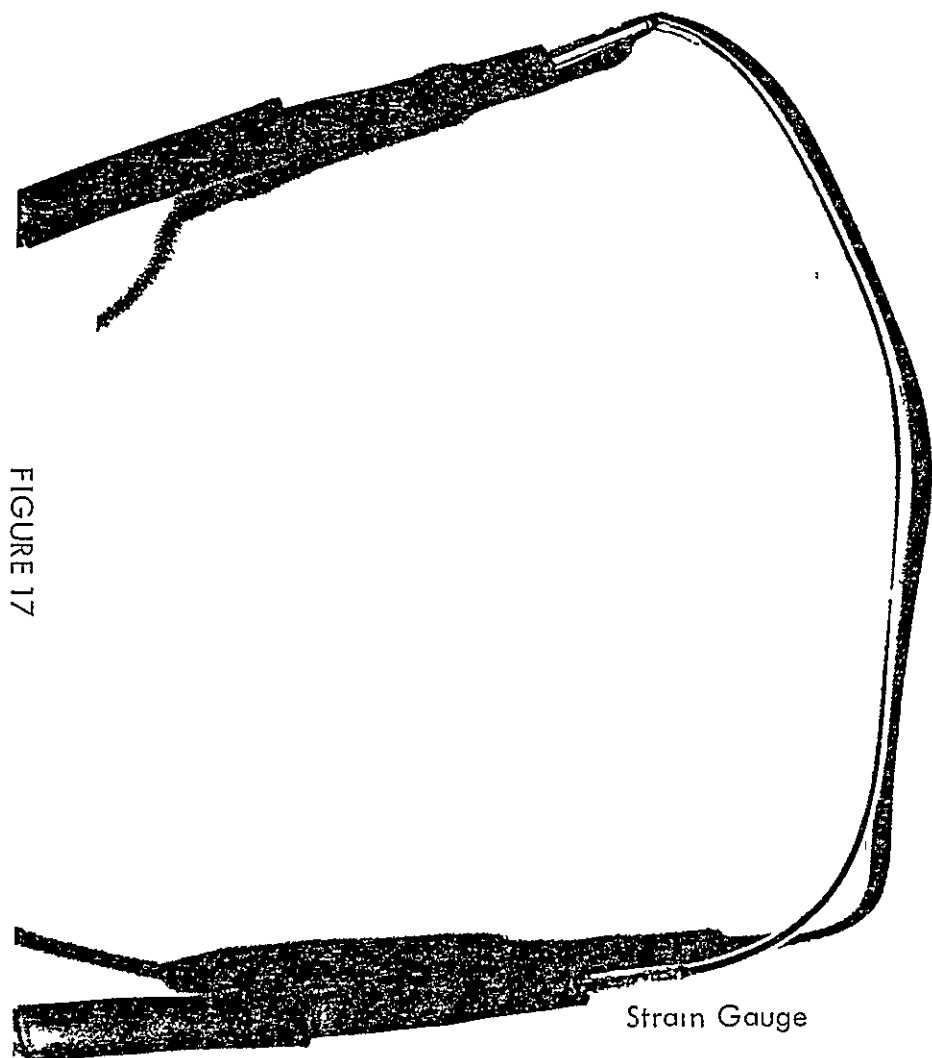
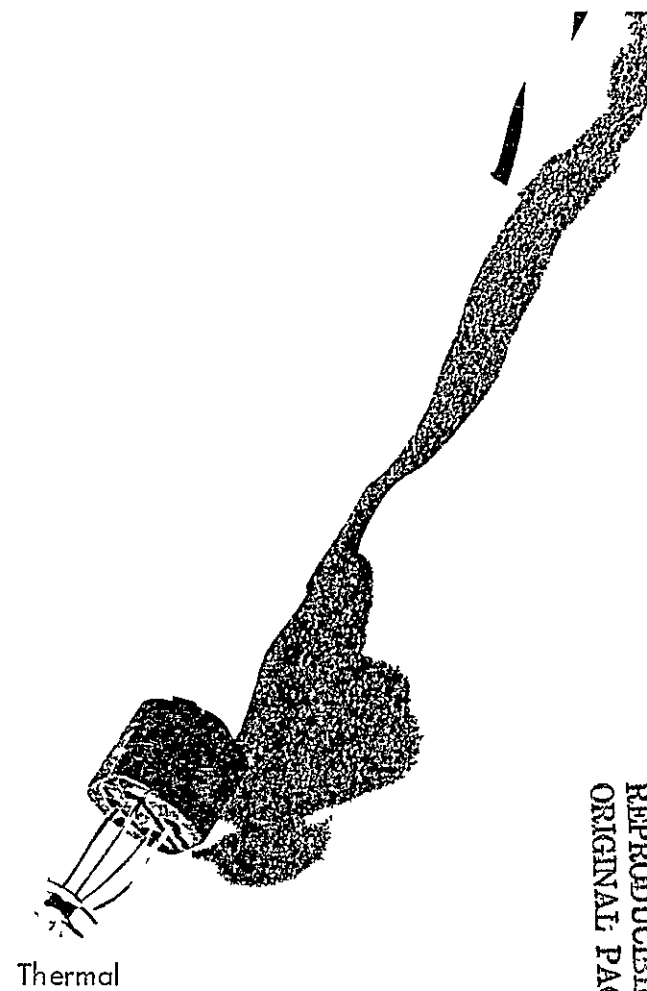


FIGURE 17

PNEUMOGRAM TRANSDUCER



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SECTION IV OPERATIONAL INSTRUCTIONS

To obtain the signals necessary for the computation of the Systolic Time Interval data the following procedures are followed

1. Power unit
2. Connect the sensors to the harness and harness to control unit
 - a. ECG leads
 - b. Strain gauge or thermo pneumogram (Respiration)
 - c. Carotid pulse transducer
 - d. Phonocardiogram microphone
3. Apply sensors to subject as indicated in the following paragraphs.

Electrocardiogram - (ECG)

Prepare three ECG electrodes with paste and annulus of double backed tape. The ground electrode is located on the right side at the level of the umbilicus. The second electrode is located on the manubrium just below the sternal notch. The third electrode is located in the standard V_5 position (Figure 1). The ECG amplitude is adjusted until the desired signal level is achieved, typically 1 - 3 volts.

Phonocardiogram

The phonocardiogram sensor is attached to the patient with an annulus of double backed tape similar to that used for the ECG electrodes. The sensor is located at the sternal border in the fourth or fifth interspace (Figure 1). Depending on the age, weight, and sex of the patient it might be necessary to search for the location which gives the best signal e.g., good second heart sound. Amplitude of the phonocardiogram signal is adjusted until the desired signal level is reached, typically 1 - 3 volts at S_2 .

Carotid Pulse Wave Sensor

This sensor (Figure 16) is placed directly over the common carotid artery to obtain the

arterial pulse wave. The strap is provided as an aid in holding the sensor in the correct position. Briefly the procedure for placement is as follows. Palpate the external carotid artery with the finger, this artery is generally located in the angle formed by the lower jaw and the neck. Place the sensor directly on the pulsating artery. Adjust the gain as desired, typically 1 - 2 volts and observe the signal. The signal should have two main characteristics which are (1) a readily discernable rapid upslope and (2) a sharply defined dicrotic notch. Figure 2 illustrates an excellent carotid pulse wave. It may be necessary to reposition the sensor several times to obtain an optimal signal. Care should be taken in not mistaking venous activity for the external carotid pulse wave. With a limited amount of practice the carotid pulse wave may be found quite readily. Either external carotid artery is suitable for use.

Respiration

- A. Strain gauge pneumogram (Figure 20) is resistance bridge, one leg of which is a mercury filled silastic tube. The strain gauge is attached with adhesive strips to the rib margin and abdomen (Figure 1). The resistance in the gauge is nulled out at the control panel and the movements of the abdomen during respiration cause a change in diameter of the silastic tube which in turn changes its resistance. The change in resistance is registered as a varying DC voltage, typically 1 - 5 volts, directly proportional to the inspiration and expiration phases of respiration.
- B. Thermopneumogram (Figure 20) is an integrated circuit which is sensitive to changes in temperature. The sensor is placed directly before the nares of the patient so that exhaled air strikes the sensor. A change in temperature is registered as the patient exhales warmed air and inhales cool ambient air. This temperature change is sensed.

by the electronics in the control unit and converted to a DC signal, typically 1 – 3 volts directly proportional to the inspiration and expiration phases of respiration.

It is important to know what phase of respiration the patient is in as the signals differ significantly with the phase of respiration. The usual convention is to determine the various parameters of the systolic time interval measurement during the expiratory phase of respiration. Two methods for the measurement of respiration are provided since in certain cases, such as a postoperative patient, one method may be more desirable than the other.

Once the various signals are satisfactory and stable, a record may be obtained from which the various systolic time interval measurements may be determined. Depending on the desired information the signals may be connected to a strip chart, light beam recorder or computer for digitization. The instrumentation is capable of driving any of these devices without degradation of the signal quality. Analysis routines are left to the individual physicians or investigators.

PARTS LIST

1. DC POWER SUPPLY

<u>Grid Designation</u>	<u>Reference Designation</u>	<u>Part Number or Value</u>	<u>Description</u>	<u>Quantity</u>
E27	C101	22 μ F	Cap	1
E27	D101	1N753A	Zener	1
	DS101	125VAC/1/3W	Lamp	1
	F101	1/2 AMP	Fuse	1
C29	PS101	\pm 15 VDC	Power Supply	1
E27	R101	220 Ω /2W	Resistor	1
	S101	DPDT	Switch-Toggle	1
	NB-101	3662	Vector Board	1
E27	SK101		PS Socket	1
E27	SK102	TI IC-016WP-7613	16 Pin IC Socket	1
E27	CSK101	Augat 8136-2968	16 Pin Component Adapter	1
	SC101-106	4X40	Screw	6
	N101-104	4X40	Hex Nut	4

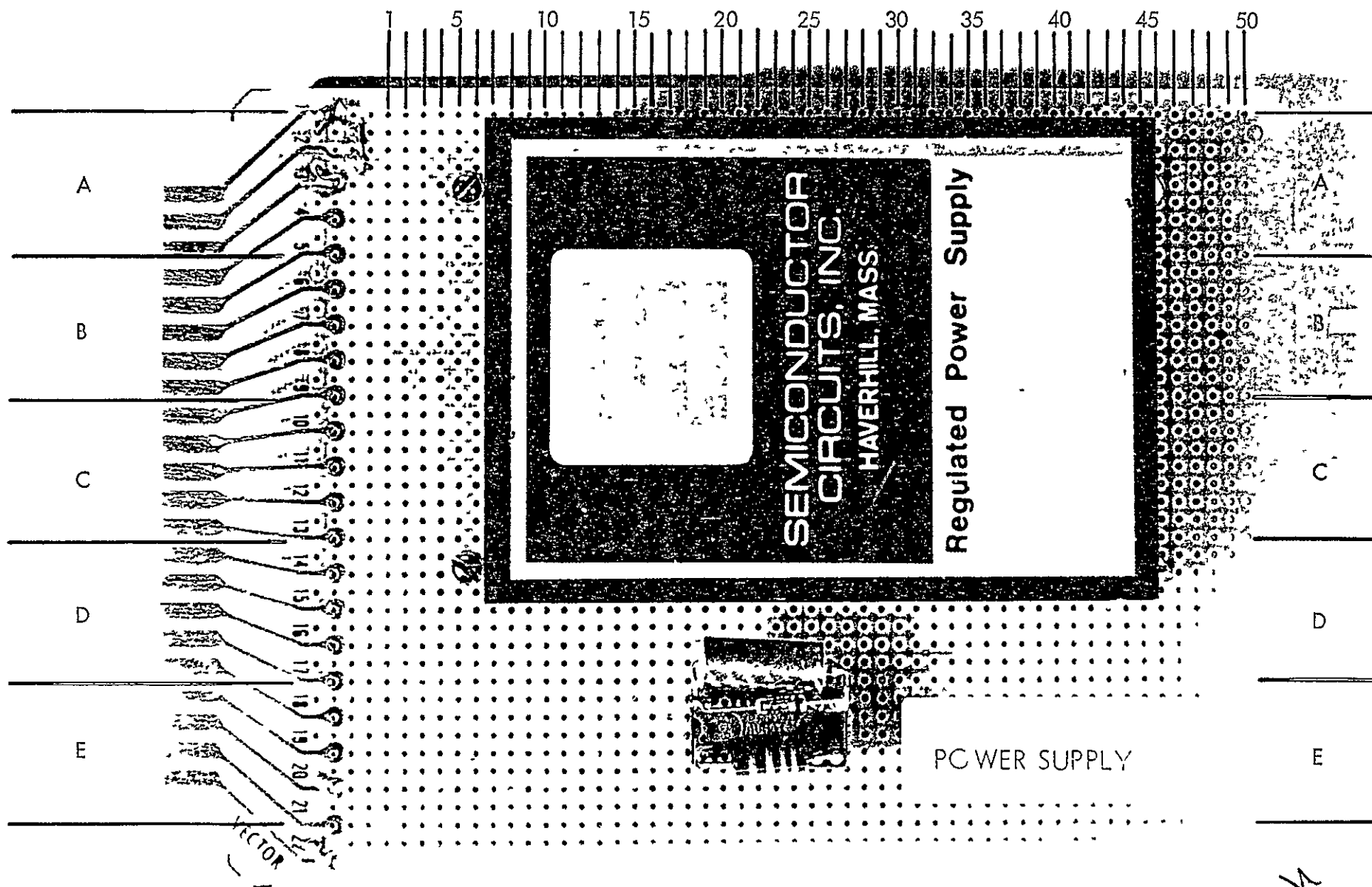
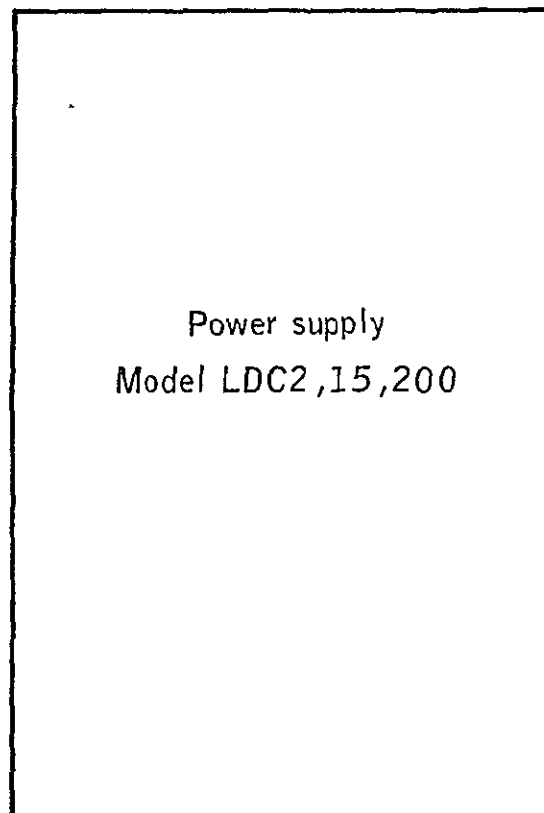


FIGURE 18

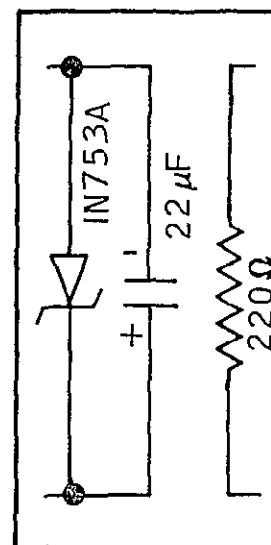
FIGURE 19

Connector end



Back view

Power supply
Board number 1.



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PARTS LIST

2. CAROTID PULSE AND PHONOCARDIOGRAPH AMPLIFIER

<u>Grid Designation</u>	<u>Reference Designation</u>	<u>Part Number or Value</u>	<u>Description</u>	<u>Quantity</u>
B22, B29	C201-C202	68 μ F	Cap	2
B33	C203	.01 μ F	Cap	1
B36	C204	.0025 μ F	Cap	1
D19, D24	C205-C206	1 μ F	Cap	2
D30	C207	.002 μ F	Cap	1
D33	C208	500 pF	Cap	1
A33, C33, A11, B11, C11, A22, C22	IC201-IC207	741	Op-Amp	7
B18, B19	R201-R202	10K	Resistor	2
B20, B21, D21	R203-R205	100K	Resistor	3
B23, B31	R206-R207	15K	Resistor	2
B24	R208	68K	Resistor	1
B25, D18	R209-R210	1M	Resistor	2
D22, B30	R211	47K	Resistor	2
B32, B35	R212-R213	300K	Resistor	2
B34	R214	150K	Resistor	1
D20, D25	R215-R216	33K	Resistor	2
D23	R217	1K	Resistor	1
D29, D32	R218-R219	560K	Resistor	2
D31	R220	270K	Resistor	1
B43, D43	R221-R222	10K	Variable Resistor	2
	R223-R224	100K	Variable Resistor	2
C39, D39, E39 A11, B11, C11, D11, E11, A22, B22, C22, D22, A33, B33, C33, D33	TP1-TP7	-	Test Points	7
	SK201-SK213	TI IC-016WP-7613	16 Pin IC Socket Com- ponent	13
	CSK201-CSK- 204	Augat 8136-2968	16 Pin Adapter	4
	VB201	3662	Vector Board	1

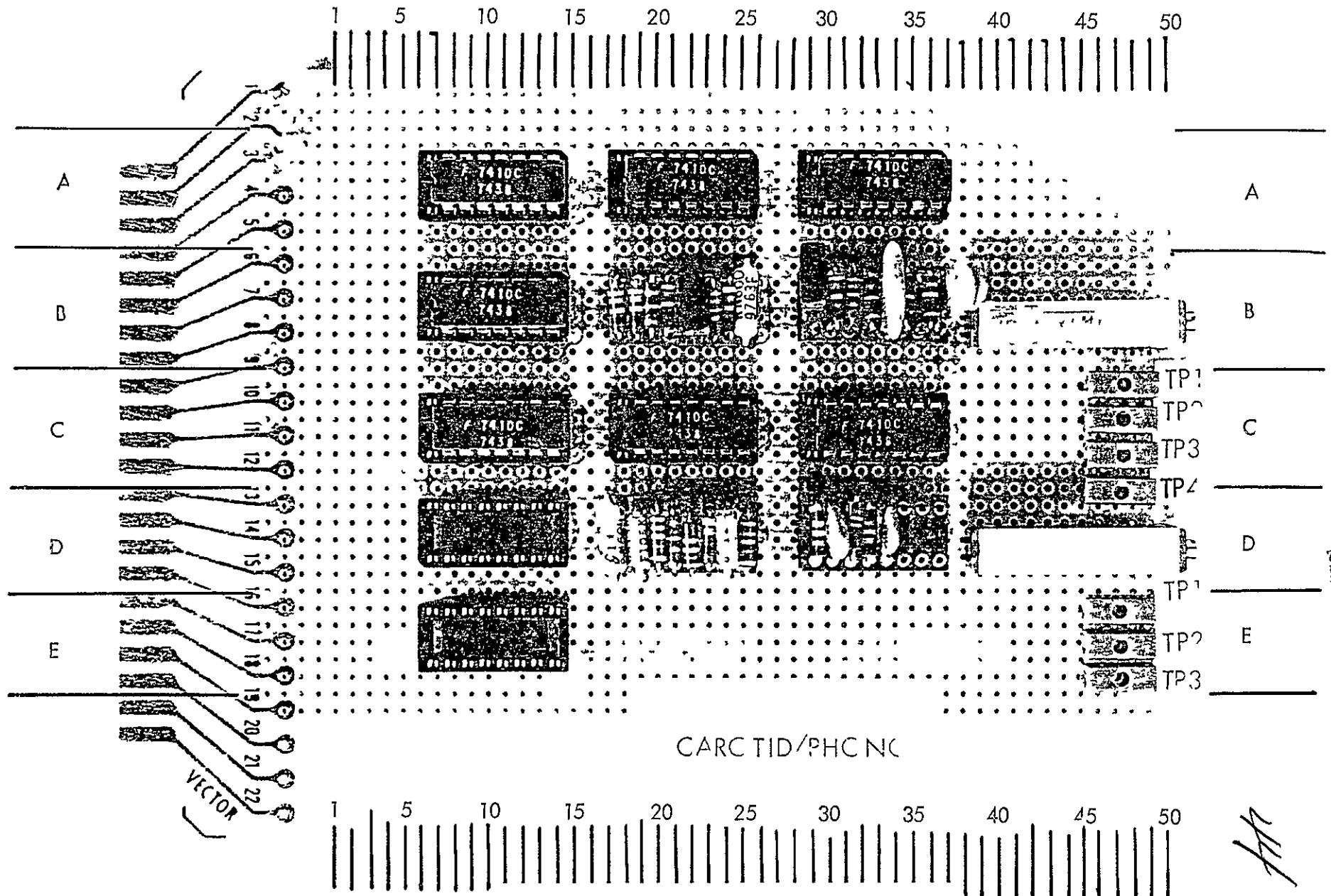


FIGURE 20

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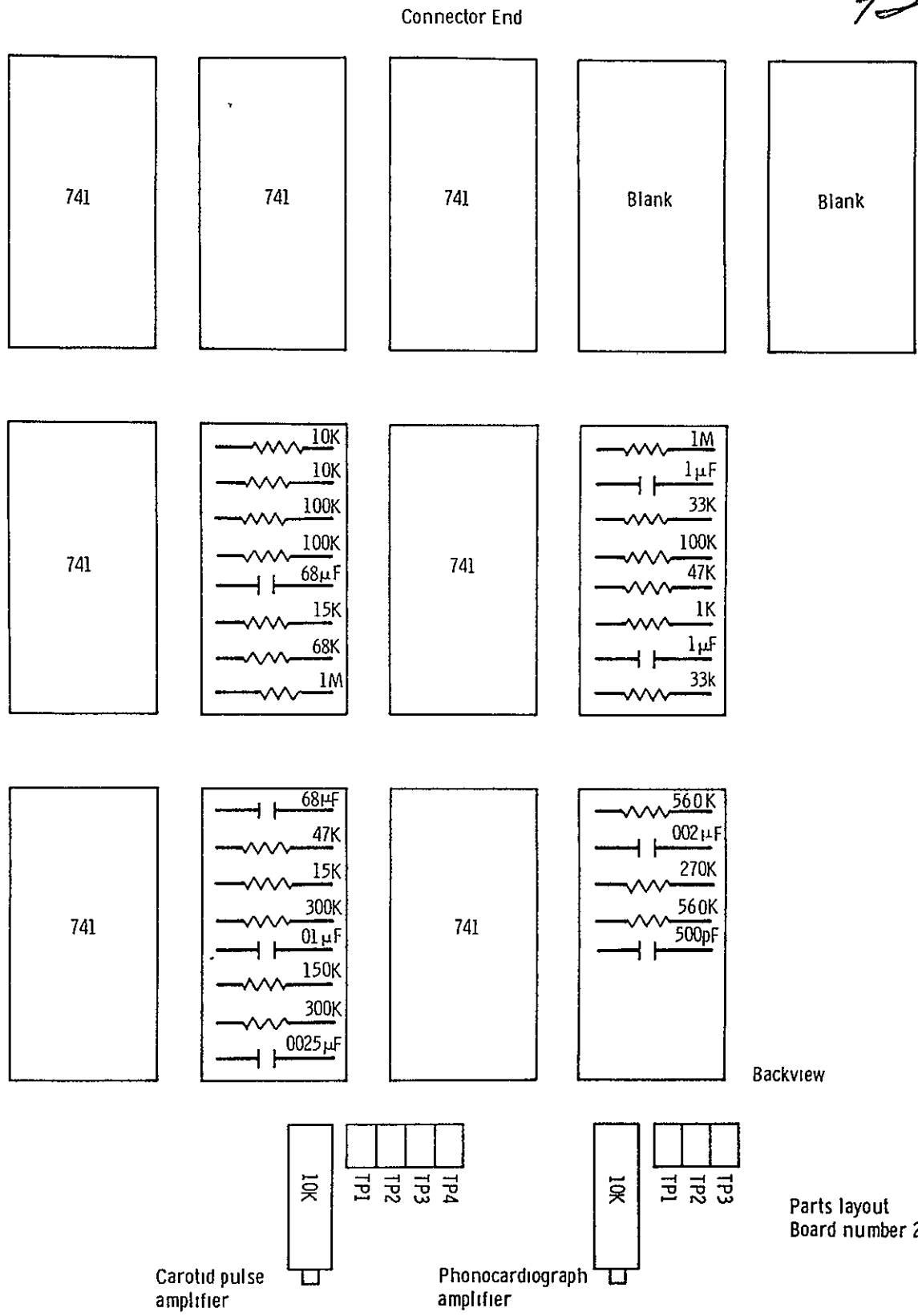


FIGURE 21

PARTS LIST

3. THERMO-PNEUMOGRAPH AND STRAIN GAUGE PNEUMOGRAPH AMPLIFIER

<u>Grid Designation</u>	<u>Reference Designation</u>	<u>Part Number or Value</u>	<u>Description</u>	<u>Quantity</u>
B18, B20, B21	C301-C303	33 μ F	Cap	3
B27, D25, D28	C304-C306	.33 μ F	Cap	3
B30, D31	C307-C308	.1 μ F	Cap	2
A8, B8, C8, A19, C19, A29, C29	IC301-IC307	741	Op-Amp	7
B15	R301	6.8K	Resistor	1
B16	R302	100K	Resistor	1
B17	R303	1M	Resistor	1
B19	R304	47K	Resistor	1
B22	R305	220K	Resistor	1
B25	R306	10K	Resistor	1
B26, B29	R307-R310	55K	Resistor	4
B28	R311-R312	27K	Resistor	2
D15	R313	10 Ω	Resistor	1
D16	R314	3.3K	Resistor	1
D17	R315	1K	Resistor	1
D18, D19	R316-R317	2.7 Ω	Resistor	2
D20, D21	R318-R319	100 Ω	Resistor	2
D22	R320	22K	Resistor	1
D26	R321	2.2K	Resistor	1
A43, C43	R322-R323	10K	Variable Resistor	2
A43	R324-R326	100K	Variable Resistor	3
	R327	20K	Variable Resistor	1
B39, C39, D39, A8, B8, C8, D8, E8, A19, B19, C19, D19, A29, B29, C29, D29	TP 1-TP7	-	Test Points	7
B15, D15, B29, D29	SK301-SK313	TI IC-016WP-7613	16 Pin IC Sockets	13
	CSK301-CSK304	Augat 8136-2968	16 Pin Component Adapter	4
	VB301	3662	Vector Board	1

PARTS LIST

4. ELECTROCARDIOGRAM AMPLIFIER

<u>Grid Designation</u>	<u>Reference Designation</u>	<u>Part Number or Value</u>	<u>Description</u>	<u>Quantity</u>
A15, A17, A18	C401-C403	33 μ F	Cap	3
C11	C404	.01 μ F	Cap	1
C14	C405	0025 μ F	Cap	1
D34	IC401	276J	150-Op-Amp	1
A6, B6, C6, D6	IC402-IC405	741	Op-Amp	4
A11, A12	R401-R402	27K	Resistor	2
A13, A14, B13	R403-R405	180K	Resistor	3
A16	R406	47K	Resistor	1
B11	R407	220K	Resistor	1
B12	R408	1K	Resistor	1
B13	R409	50K	Resistor	1
B14, B15, B16	R410-R413	196K	Resistor	4
B17	R414	976K	Resistor	1
B18, C12	R415-R416	300K	Resistor	2
C13	R417	150K	Resistor	1
F8, F11, F14, F17	R418-R421	10K	Variable Resistor	4
	S1	SPST	N.O. Push Button	1
	S2	SPST	Switch Rotary	1
	TP 1-TP4	-	Test Points	4
D34	SK401	AC1033	ISO-Op-Amp Socket	1
A6, B6, C6, D6, A15, B15, C15, D15	SK402-409	T1 IC-016WP-7613	16 Pin IC Socket	8
A15, B15, C15	CSK401-CSK408	Augat 8136-2968	16 Pin Component Adapter	3
	VB401	3662	Vector Board	1
	SC401-406	6X32	Screw	6
	N401-404	6X32	Hex Nut	4

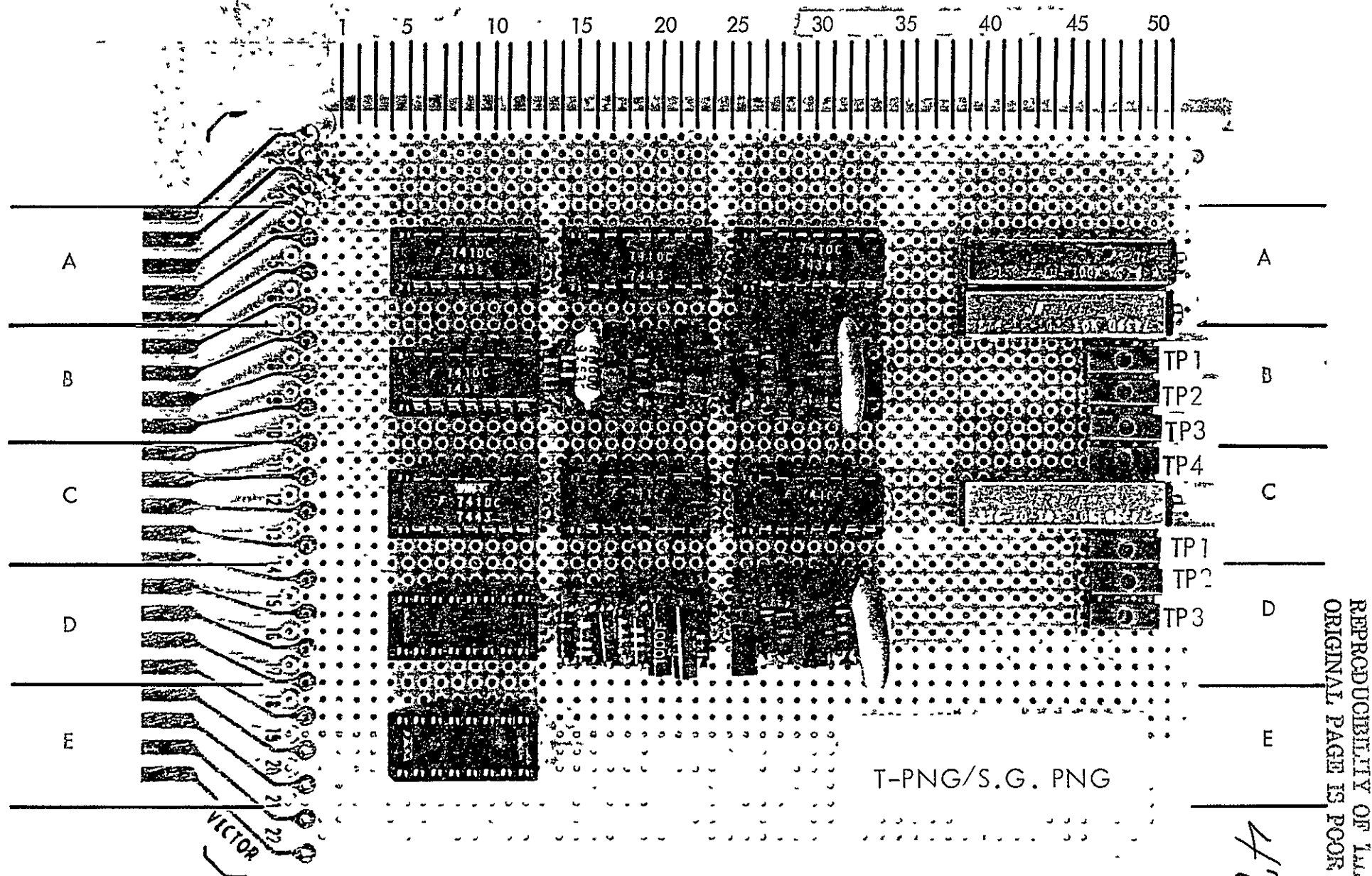
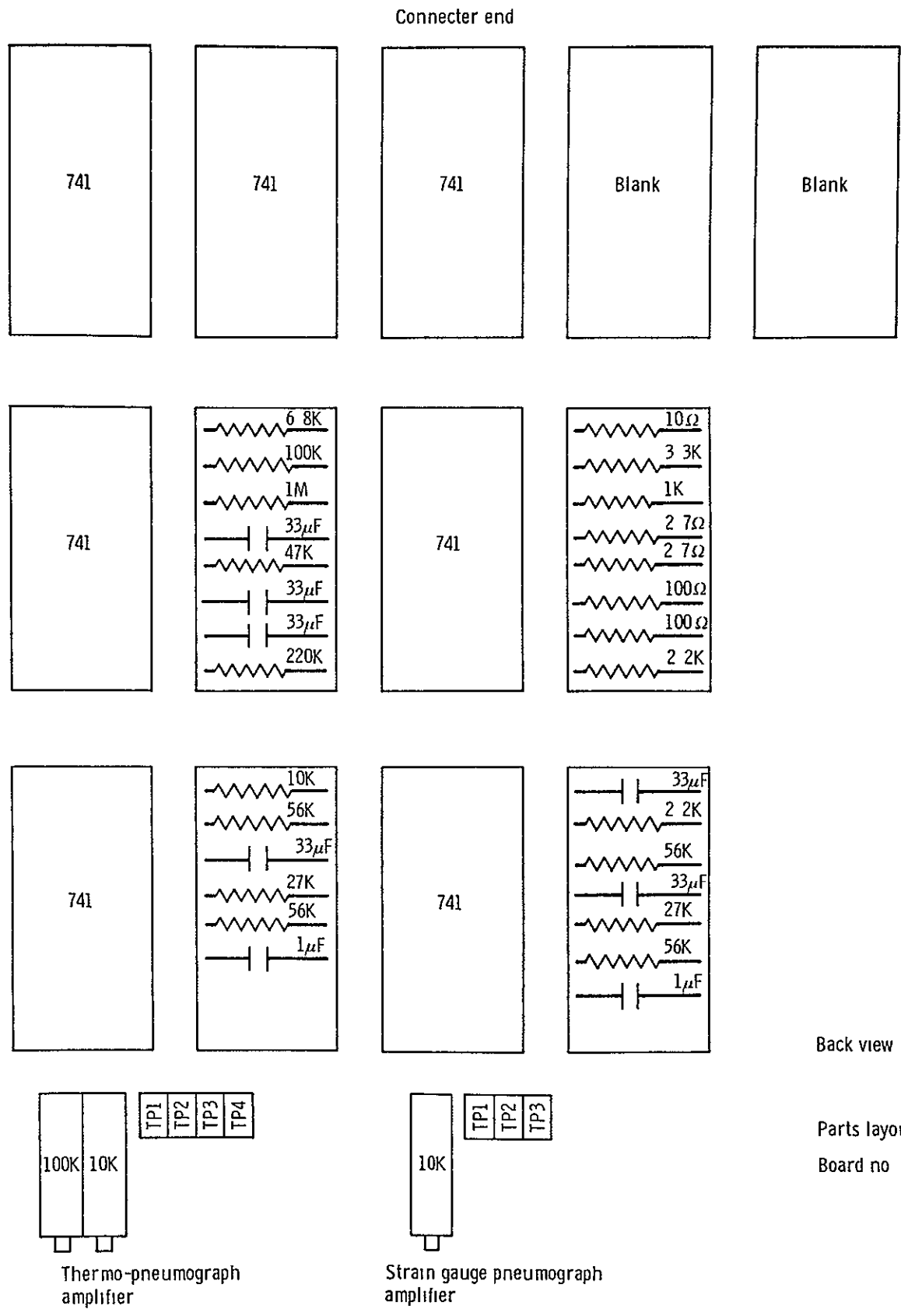


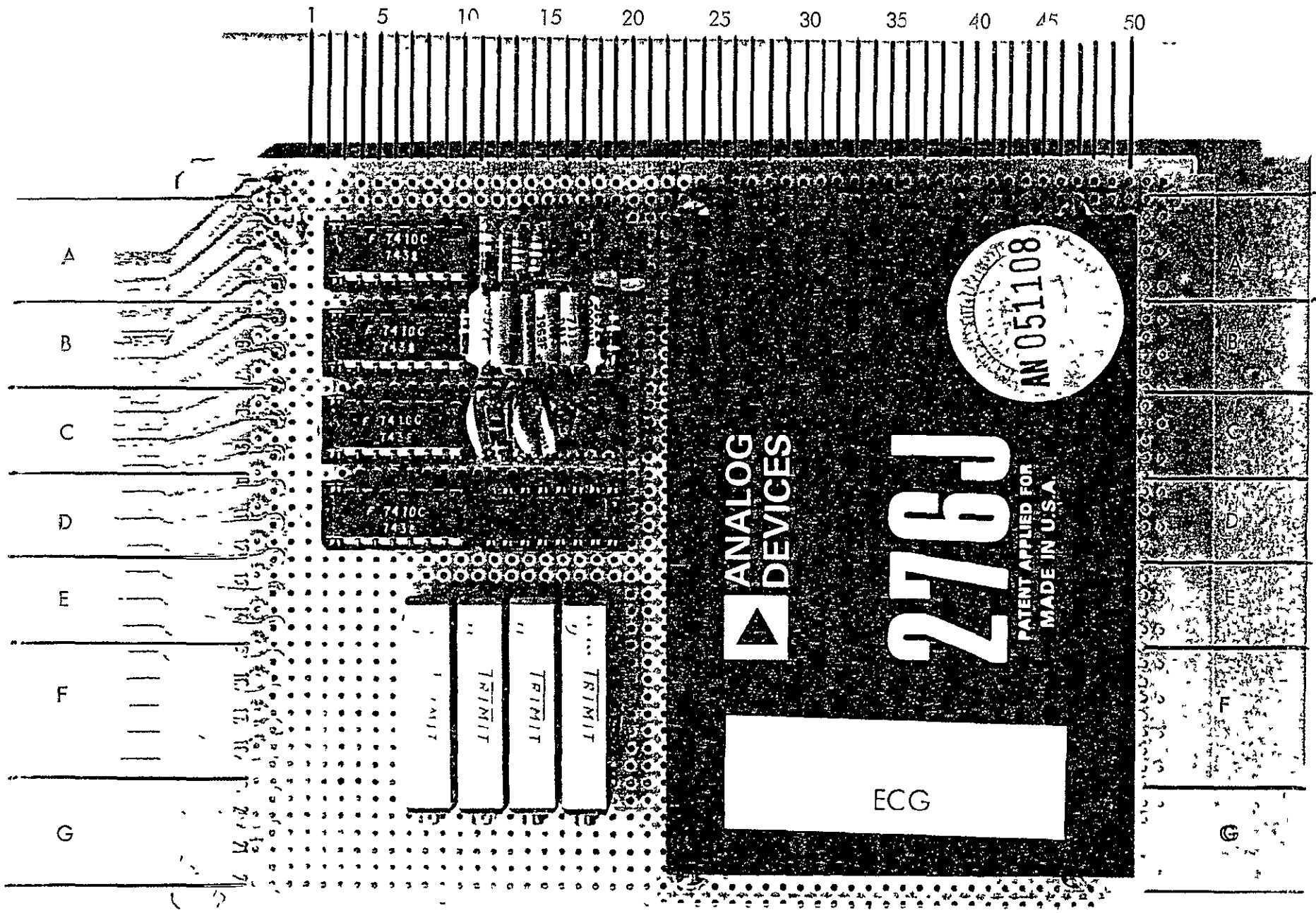
FIGURE 22

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FIGURE 23





REPRODUCIBILITY OF THE
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FIGURE 24

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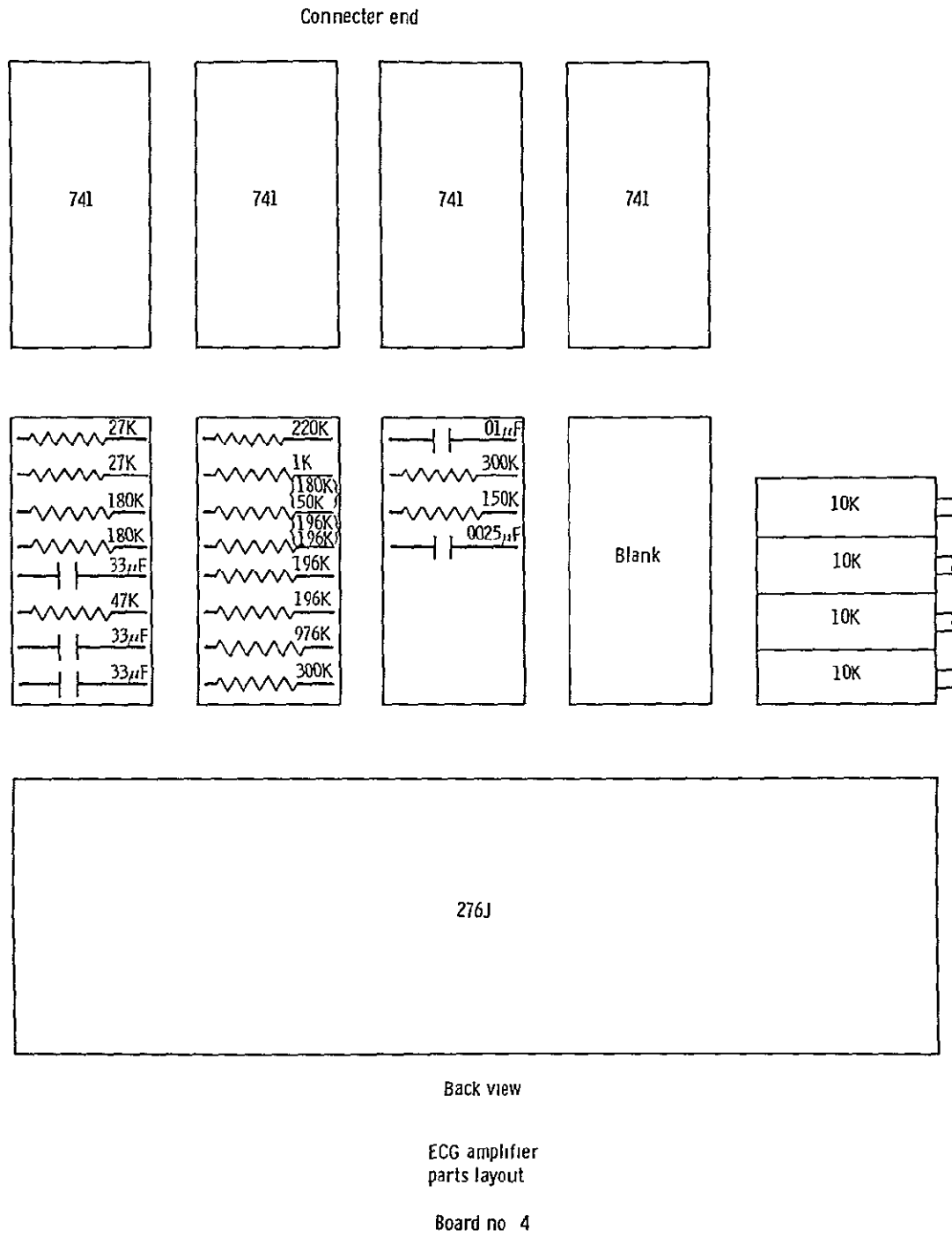


FIGURE 25

BIBLIOGRAPHY

The following bibliographic references are not intended to be a definitive reference source. It is intended solely as a beginning guide to the history and varied uses of Systolic Time Interval information. However, interested parties should find the references more than adequate as a beginning set of references.

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PROJECT PERSONNEL

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Biomedical Engineer - William Crosier

Electronics and Construction Technician - John Donaldson

Report Preparation and Graphics - Mary Taylor

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Figure 25 Electrocardiogram Amplifier - Component Layout